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AN OPERATIONAL FLIGHT TEST EVALUATION OF A LORAN-C NAVIGATOR.(U)

MAR 77 M HUGHES, R J ADAMS

DOT-CG-63154-A

UNCLASSIFIED

USCG-D-9-77

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Report No. CG-D-9-77

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AN OPERATIONAL FLIGHT TEST EVALUATION OF A LORAN-C NAVIGATOR



March 1977

Final Report



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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
United States Coast Guard
Office of Research and Development
Washington, D.C. 20590

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1. Report No. 19 18 US CGAD-9-77 ✓	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle 6 An Operational Flight Test Evaluation of a Loran-C Navigator.		5. Report Date 19 March 1977	6. Performing Organization Code
7. Author(s) 10 M. Hughes and R.J. Adams		8. Performing Organization Report No. 15 128p.	
9. Performing Organization Name and Address Systems Control, Inc. (Vt) ✓ 1801 Page Mill Road Palo Alto, California 94304		10. Work Unit No.	11. Contractor or Grant No. 15 DOT-CG-63154-A new
12. Sponsoring Agency Name and Address Department of Transportation United States Coast Guard Office of Research and Development Washington, D.C. 20590		13. Type of Report and Period Covered 9 Final Report - 9	
14. Sponsoring Agency Code			
15. Supplementary Notes Report prepared by Champlain Technology Industries, A Division of Systems Control, Inc. (Vt), a Subsidiary of Systems Control, Inc., Palo Alto, California			
16. Abstract This report presents the results of an operational test and evaluation of a Loran-C navigation system. The tests were performed in a Coast Guard HH-52A helicopter from 21 September to 19 October 1976. The flight test profiles, procedures and test objectives were developed to determine the applicability of the prototype Loran-C navigator to Coast Guard operations as well as to assess the functional and accuracy performance of the Loran-C navigator operating as an area navigation system in the National Airspace System. The operational testing reported in this document includes search and rescue missions as well as surveillance and enforcement missions. The former consisted of evaluating the Loran-C navigator during creeping line, sector, and expanding square search patterns. The latter involved performing low altitude hovers over fixed and movable objects and documenting Loran-C accuracy and repeatability. This latter data is also directly applicable to the operations of the off-shore oil industry. The functional and accuracy data testing performed is directly applicable to operations of Loran-C equipped aircraft in the National Airspace System (NAS). Enroute, terminal and approach data was taken near the Cape May, New Jersey region of the United States. Terminal area routes tested were chosen from the proposed area navigation routes developed for New York-Kennedy for the 1977 to 1982 time period. The NAS testing was performed at the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, New Jersey. The conclusions reached were: the navigator performed accurate, repeatable and operationally meaningful search and rescue missions with superior performance compared to current navigation techniques; the compatibility of a Loran-C navigation system with both present and future planned area navigation routes and procedures was demonstrated; the accuracy was demonstrated to be within AC 90-45 limits, and performance was satisfactory in off-shore operations. 389 333			
17. Key Words Helicopter Navigation Loran-C Navigator System Operational Evaluation AC 90-45A		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 120	22. Price

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The analysis of the performance of the Loran-C navigator system for both Coast Guard missions and as an area navigation system operating in the National Airspace System (NAS) is summarized in this section. In order to develop the proper perspective and to understand the impact of this brief summary of results this section includes a statement of program objectives and an explanation of the method of approach used to test the Loran-C navigator system.

1.1 GENERAL PROGRAM OBJECTIVES

The operational evaluation of the airborne Loran-C navigator system was designed to satisfy several general, or overall, objectives. These can be summarized as follows:

- 1) To obtain operational data on realistic Coast Guard Search and Rescue (SAR) missions which can be used to determine the capabilities of the Loran-C system in relation to operational requirements and constraints.
- 2) To acquire accuracy data using the Loran-C navigator system which documents the absolute accuracy and the statistical error probability for use in Coast Guard surveillance and enforcement missions.
- 3) To evaluate the suitability of the Loran-C navigation system in the current VOR/DME NAS environment as well as the compatibility of Loran-C with the existing and planned NAS area navigation constraints.
- 4) To demonstrate the applicability of Loran-C navigation for use where VOR/DME coverage is inadequate, such as in off-shore helicopter operations.

1.2 METHOD OF APPROACH

The basic test program consisted of two major categories of dedicated flight testing. These were defined as Operational Testing and NAS Testing. The operational category included all of the various Coast Guard missions previously mentioned in Section 1.1, specifically, three SAR patterns (creeping line, expanding square and sector search), and three different surveillance and enforcement helicopter hover missions (over three buoys moored at 16, 52 and 90 foot depths, a lighthouse located approximately in the center of Delaware Bay, and a fixed landmark). These data validated the feasibility of verifying buoy position using a Loran-C equipped helicopter as well as the previous objectives for surveillance and off-shore helicopter operations. The NAS testing included enroute legs of 24 and 37 nm, terminal area testing on Standard Instrument Departure (SID) and Standard Terminal Arrival Route (STAR) segments, and non-precision approach testing. The terminal area test routes used were derived from those developed for New York-Kennedy as described in Reference 1. The final approach testing was performed using the Loran-C navigator to perform a standard non-precision instrument approach to Runway 4 at the FAA National Aviation Facilities Experimental Center. The Loran-C lateral and longitudinal navigation information for cross track error

and distance-to-go to the Missed Approach Point was recorded to obtain approach accuracy information. During the NAS testing the Loran-C navigator was operated in the latitude/longitude input mode according to the pilot's handbook supplied by the manufacturer. No special initialization or system calibration procedures were utilized during enroute or terminal area navigation. The purpose of this constraint was to simulate in the most realistic fashion the manner in which Loran-C is expected to be used in the real world NAS operational environment. However, in addition to the approach accuracy data which was taken using charted, non-updated pre-flight waypoint lat/long data (6 approaches), data was also taken on approaches using charted waypoint lat/long data updated at the gate prior to take-off (6 approaches) and using time difference waypoint input data (6 approaches). This was done to demonstrate all levels of non-precision approach accuracy available using the Loran-C navigator system.

Figure 1.1 summarizes the overall Loran-C flight test matrix. The variables of primary importance in this matrix are the number of flights, the flight hours and the type of testing. In addition to the forty hours of flight testing each flight crew received a minimum of one familiarization flight. The approximate duration of this initial Loran-C flight training was one hour per crew. Six pilots were selected for this experiment and grouped into 3 test crews. Each subject pilot performed a final SAR scenario flight to demonstrate proficiency in procedures for utilizing the Loran-C equipment for sector, expanding square and creeping line searches prior to the first NAS test flight. This precaution provided additional exposure to the Loran-C navigator system prior to the imposition of a higher workload during the terminal and approach phases of NAS testing. The orientation and familiarization flights were also used for shakedown and debugging of the airborne data acquisition system, post flight data validation technique, tracking radar coordination, time correlation, and lock-on procedures.

As can be seen in Figure 1.1, the total experimental program duration consists of 16 data gathering flights which required approximately 40 flying hours. The three basic SAR patterns were flown a total of fourteen times — five creeping lines, four sector searches and five expanding squares. As noted on Figure 1.1, these Loran-C SAR patterns were compared not only to the desired or specified search profile, but also to two SAR profiles performed using conventional VOR/DME navigation for comparison during the Loran-C evaluation.

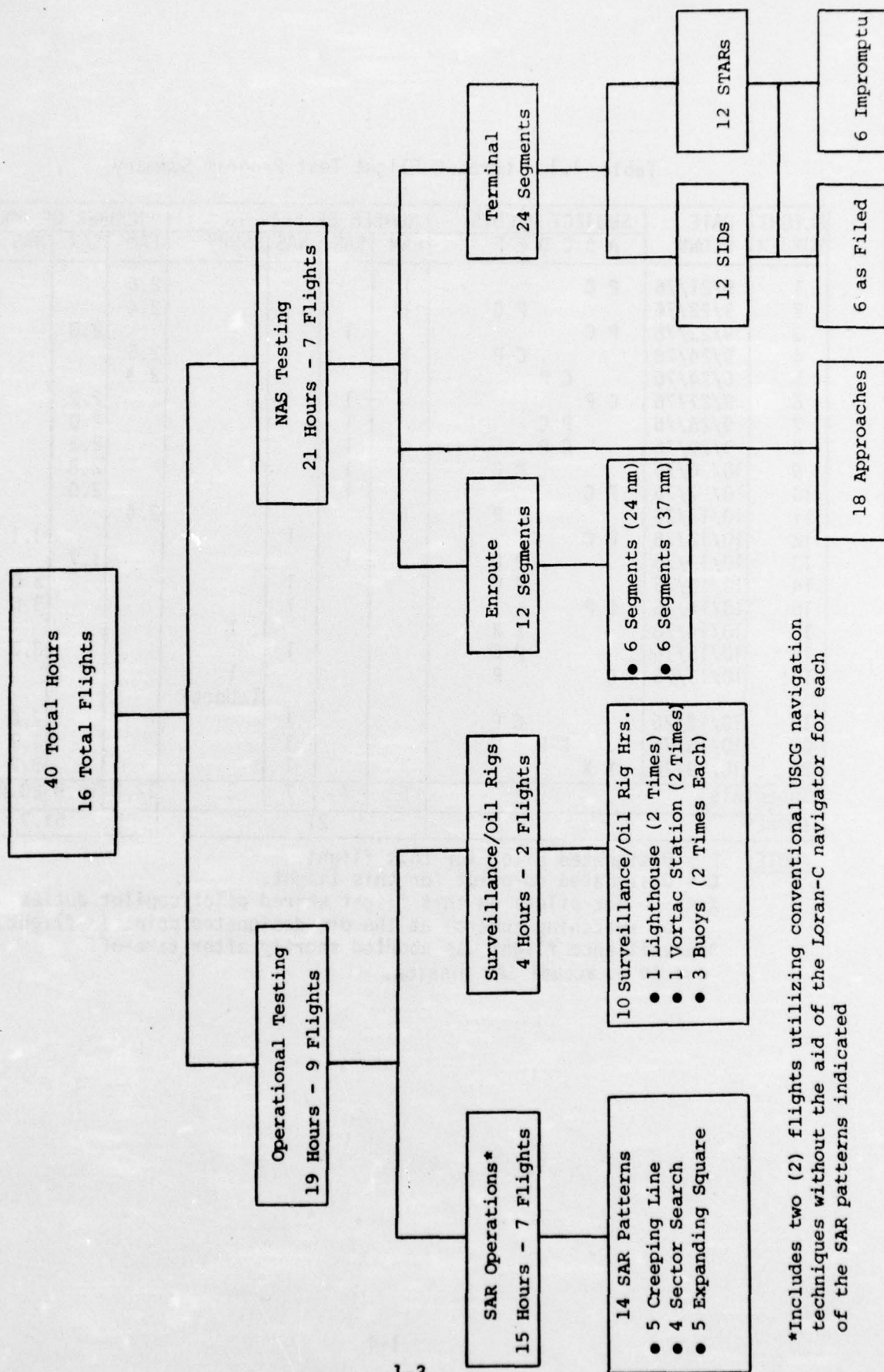
The subject pilots (six total) each executed five separate surveillance hovers over surveyed, pre-specified fixes. These data were used to determine and document Loran-C position fixing accuracies over fixed and movable targets.

NAS testing consisted of twelve enroute segments, twenty-four terminal area segments and eighteen approaches. These sample sizes were chosen to insure adequate statistical data reliability as described in Reference 2. The data was reduced into total system error, flight technical error and airborne equipment error statistics for each route segment. These statistics were then combined across flights to develop summary data for enroute, terminal and approach Loran-C accuracy demonstration.

Table 1.1 shows the subdivision of flight sequence by subject pilot and flight type. This table provides cross validation of the total number of flights and flight hours by documenting the flights per pilot.

A more detailed description of flight profiles, pattern definition, and test scenarios for the SAR, Surveillance and NAS testing is presented in Sections 4.2, 4.3 and 4.4.

Figure 1.1 Overall Loran-C Flight Test Matrix



*Includes two (2) flights utilizing conventional USCG navigation techniques without the aid of the Loran-C navigator for each of the SAR patterns indicated

Table 1.1 Loran-C Flight Test Program Summary

FLIGHT NUMBER	DATE FLOWN	SUBJECT PILOTS						NUMBER OF FLIGHTS				NUMBER OF HOURS			
		A	B	C	D	E	F	FAM	SAR	NAS	SURV	FAM	SAR	NAS	SURV
1	9/21/76	P	C					1				2.6			
2	9/22/76					P	C	1				2.4			
3	9/23/76	P	C						1				2.0		
4	9/24/76					C	P	1				2.5			
5	9/24/76			C	P			1				2.3			
6	9/27/76	C	P						1				2.2		
7	9/28/76					P	C		1				2.0		
8	9/29/76					C	P		1				2.2		
9	10/ 6/76						P	C		1			2.8		
10	10/ 7/76	P	C						1				2.0		
11	10/12/76					C	P	1				2.4			
12	10/12/76	P	C							1				3.1	
13	10/13/76					P	C		1				1.7		
14	10/13/76					P	C			1				3.0	
15	10/14/76	C	P							1				3.0	
16	10/14/76					X	X				1				2.6
17	10/15/76					P	C			1				3.0	
18*	10/15/76	C				P					1 (abort)				1.2
19	10/18/76					C	P			1				2.8	
20	10/18/76			C	P					1				2.7	
21	10/19/76	X	X							1				3.2	
Subtotals								5	7	7	2	12.2	14.9	20.8	3.8
TOTALS								21				51.7			

/NOTE/ P = Designated pilot for this flight.
 C = Designated co-pilot for this flight.
 X = Subject pilots on this flight shared pilot/copilot duties
 by switching control at the pre-designated point in-flight.
 *Surveillance flight was aborted shortly after take-off
 due to an actual SAR mission.

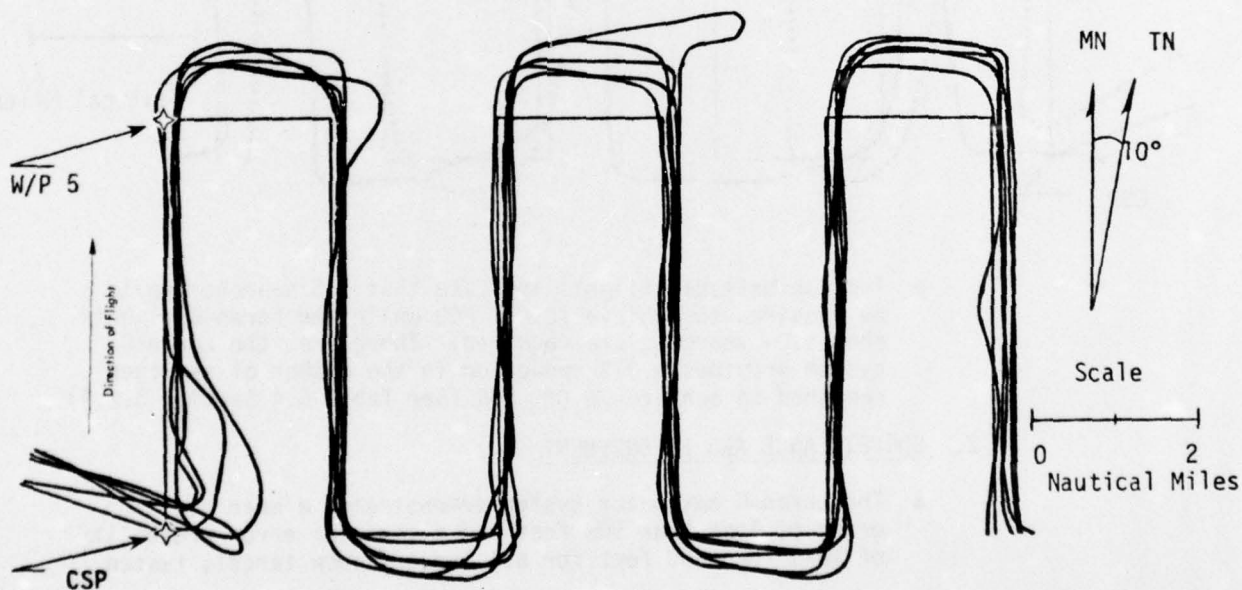
1.3 RESULTS AND CONCLUSIONS

This section presents a generalized summary or overview of the primary results and conclusions which may be found in Sections 6.0 and 7.0 respectively. A detailed analysis and expanded discussion of each of these major results is presented in Section 5.0. The intent here is to provide answers to the basic quantitative and qualitative operational evaluation objectives which have been derived as a result of the comprehensive test program described in the method of approach. Each major conclusion is followed by a typical graphical presentation which substantiates the statement made by using representative results from the flight test program. For a detailed analysis and presentation of all the tested SAR missions and NAS routes see Section 5.0.

1. SEARCH AND RESCUE

- The Loran-C navigator system performed accurate, repeatable and operationally meaningful search and rescue missions including creeping line, sector and expanding square search patterns.
- The probability of detection (POD) using Loran-C on a creeping line search was calculated as 77.33% for the first search compared to a desired value of 78.00% (from Reference 7).

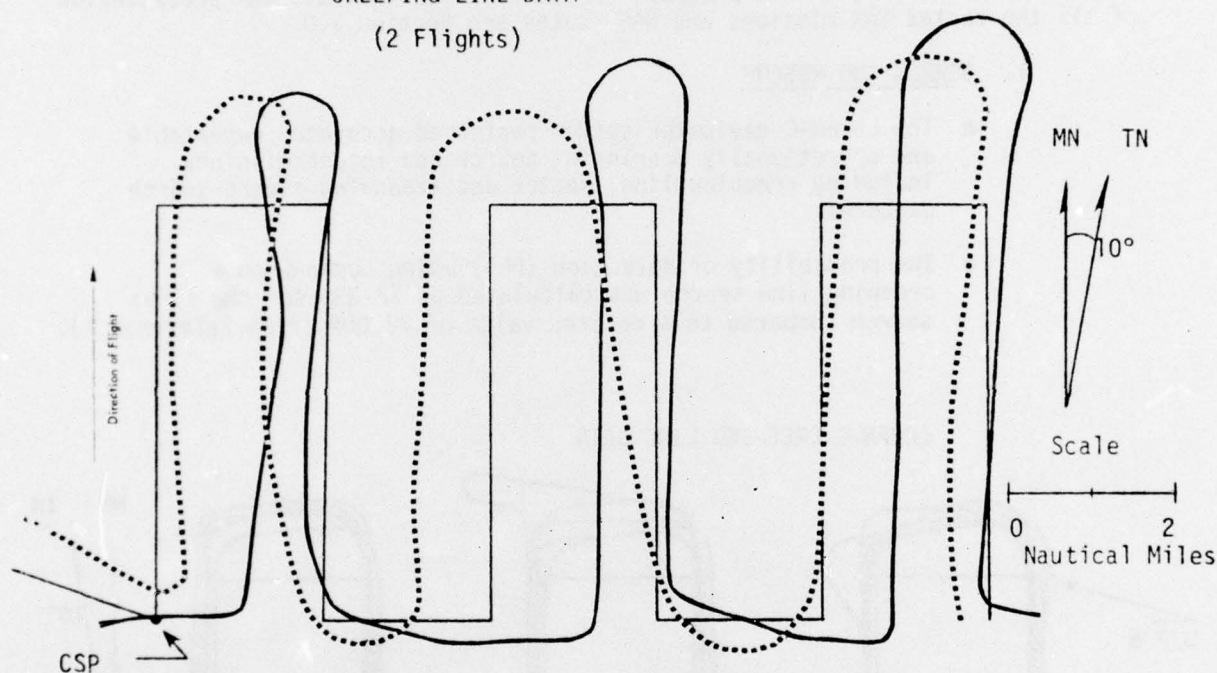
LORAN-C CREEPING LINE DATA



- The Loran-C navigator system demonstrated superior performance on all search and rescue patterns compared to conventional VOR/DME navigation techniques.
- The POD using conventional VOR/DME was calculated as 68.4% on the first pass.

CONVENTIONAL VOR/DME
CREEPING LINE DATA

(2 Flights)



- The conventional flights indicate that 1.5 searches would be required to achieve 78.00% POD while the Loran-C flights show 1.04 searches are required. Therefore, the Loran-C system provides a 31% reduction in the number of searches required to achieve 78.00% POD (See Table 5.4 Section 5.2.1).

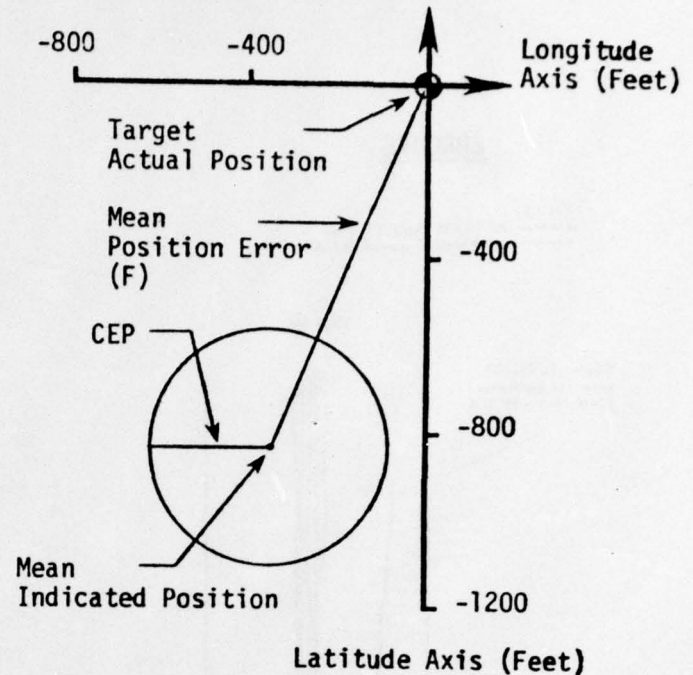
2. SURVEILLANCE AND ENFORCEMENT

- The Loran-C navigator system demonstrated a mean position error of less than 900 feet and a circular error probability of less than 400 feet for all surveillance targets tested.
- For a single charted buoy or oil rig location, the demonstrated mean Loran-C position error was 896 feet with a circular error probability of $(114.3 \pm 3\%)$ feet.

LORAN-C SURVEILLANCE ACCURACY

All Moored Buoys
F = 896.0 feet
CEP = 295.9 feet \pm 3%

NOTE: Moored plus
Fixed Targets showed
F = 734.8 feet
CEP = 377.0 feet \pm 3%



- Loran-C demonstrated the capability of providing accurate and repeatable navigation in an offshore environment.

3. NAS/AC 90-45A COMPATIBILITY TESTING

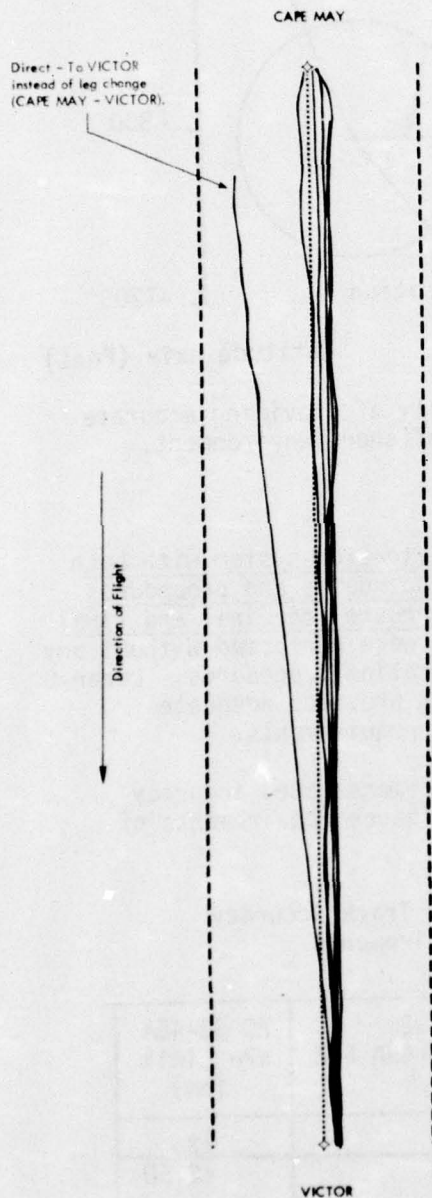
- The compatibility of a Loran-C navigation system with both present and planned area navigation routes and procedures was adequately demonstrated for enroute, terminal and final approach operations. These tests were performed without any special system update or initialization procedures. Loran-C meets all present requirements and provides adequate capability for anticipated future requirements.
- Table 1.2 summarizes the Loran-C demonstrated accuracy requirements compared to the compliance requirements of AC 90-45A.

Table 1.2 Loran-C Total System Cross Track Accuracy Compared to AC 90-45A Requirements

Flight Phase	Measured Bias $\pm 2\sigma$ (nm)		Calculated $\pm 2\sigma$ Using AC 90-45A FTE (nm)	AC 90-45A $\pm 2\sigma$ Limit (nm)
Enroute	Bias	$\pm 2\sigma$	$\pm 2\sigma$	$\pm 2\sigma$
	0.10	± 0.56	± 2.08	± 2.50
Terminal	0.03	± 0.51	± 1.11	± 1.50
Approach	-0.38*	± 0.10	± 0.50	± 0.60
* Worst case see section 5.1.4 for discussion				

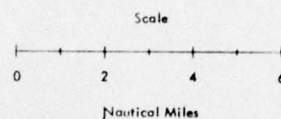
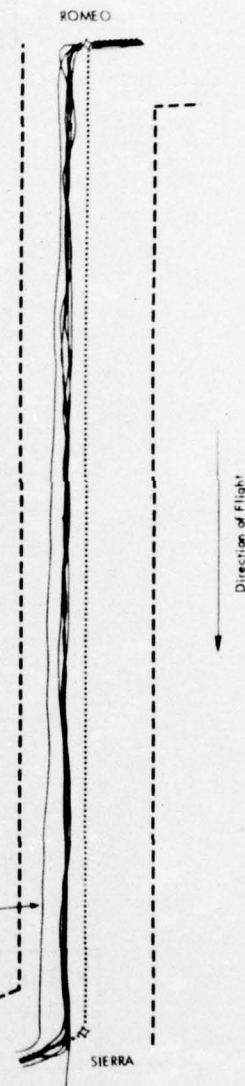
ENROUTE

NOTE
 --- AC 90-45A Limits (± 2.5 nm)
 ——— E-AIR Radar Crosstrack (Actual)

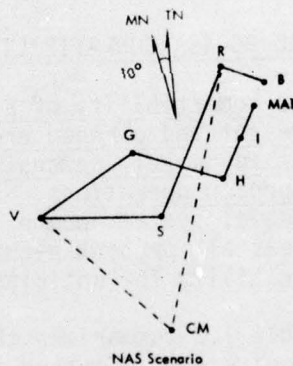


TERMINAL

NOTE
 --- AC 90-45A Limits (± 1.5 nm)
 ——— E-AIR Radar Crosstrack (Actual)



Overall NAS Route

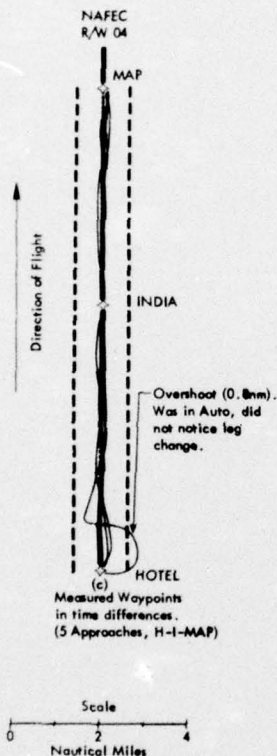


This Entire Departure NO GOOD
 Due to uncalibrated Radar Tracking

- The Loran-C navigator system demonstrated accurate (.06 nm mean and 0.12 nm two sigma) performance in flying non-precision approaches using measured time/difference waypoint coordinates.

FINAL APPROACH

NOTE
 AC 90-45A Limits (± 0.6 nm)
 E-AIR Radar Crosstrack (Actual)



Approach Data Using Two Other Waypoint Input Modes Is Shown On Figure. 5.4

- The accuracy of the Loran-C navigation system in the current National Airspace System VOR/DME environment was demonstrated to be within AC 90-45A limits.

4. OFF-SHORE OIL RIG OPERATIONS

- The Loran-C navigator system performed satisfactorily in off-shore surveillance and search and rescue missions where VOR/DME coverage is inadequate. This performance should be of special interest to off-shore helicopter operators.

2.0

INTRODUCTION

The implementation of Loran-C as the primary navigation system suitable for United States Coast Guard airborne operations requires that several functional, operational and accuracy questions be resolved. In order to organize these questions in a logical sequence and to minimize the effort required to document the performance of the Loran-C navigator, a methodical and comprehensive flight test program was developed. This document describes the detailed results of the airborne Loran-C navigator system operational test and evaluation.

2.1 BACKGROUND INFORMATION

The flight test program was performed between September 21 and October 19, 1976. The testing included operational Coast Guard missions as well as compatibility testing in the National Airspace System (NAS) environment. Off-shore testing, enroute, terminal area and non-precision approach testing was performed in the northeast section of the United States.

The Coast Guard operational testing consisted of Search and Rescue (SAR) and Surveillance and Enforcement missions. The SAR missions included creeping line, expanding square, and sector search patterns. These patterns were performed under simulated search conditions by three crews (six pilots). Each pattern was flown several times to document repeatability and accuracy. The surveillance and enforcement missions were flown both off-shore over the Atlantic Ocean and within the confines of Delaware Bay. These data were used to document the performance of the airborne Loran-C navigator system during typical Coast Guard mission applications. Successive SAR flight profiles were overlaid to demonstrate suitability and repeatability of the patterns as well as acceptability of the area covered during each search. In addition, the surveillance data were aggregated to obtain worst case mean position errors and circular position error probability predictions.

The NAS testing consisted of enroute, transition, terminal maneuvering and non-precision approach data. The enroute data were recorded while departing and returning to the Cape May Air Station. Terminal area and non-precision approach data were obtained in the terminal airspace of the National Aviation Facilities Experimental Center (NAFEC) at Atlantic City, New Jersey. Both pre-programmed ("as filed") and impromptu routing were evaluated for operational compatibility and acceptability in the NAS environment. A data base was recorded during these experiments which should be acceptable for demonstration of compliance with the area navigation accuracy requirements of FAA Advisory Circular 90-45A, "Approval of Area Navigation Systems for Use in the U.S. National Airspace System". This data base, properly coordinated, could be submitted in fulfillment for certification of the Loran-C navigator system for area navigation operations. This data base was collected with the Loran-C navigation system operating in the latitude/longitude mode and without any extraordinary system initialization or updating ("tweaking") on a day-to-day basis. This was a necessary precaution to insure the maximum applicability to expected or normal Loran-C operations in the NAS.

The Loran-C navigator system evaluation was performed using a dedicated Coast Guard HH-52A helicopter. Both ground based radar tracking data and airborne Loran-C data were automatically recorded as a part of this test program. The ground referenced data were obtained using the NAFEC "Extended Area

Instrumentation Radar" (EAIR). EAIR is a precision, C-band tracking radar which provides the slant range, azimuth angle and elevation angle of an aircraft (1 square meter) within a range of 100 nautical miles when operating in the skin tracking mode, with a maximum distance of 190 nautical miles when operated in the beacon tracking mode. (All of the Loran-C test flights reported herein were tracked in beacon tracking mode). The slant range obtained by the EAIR facility is accurate within 20 yards and the azimuth angle and elevation angle are accurate within 0.011 degrees. For example, at 50 miles the accuracy would be 20 yards in range and 20 yards in azimuth and elevation. The antenna can be directed as low as minus one and one-half degrees in elevation.

Flight crews were selected and trained in the utilization of the Loran-C equipment prior to initiation of test data collection. However, it should be noted that the flight crew members used had no prior familiarity with the Loran-C system and no special digital computer interface experience or training. That is, no formal long term flight crew training program was used or considered necessary. Classroom orientation and instruction (one day) with a limited amount of "hands-on" time was the extent of pre-test training. In addition to the pre-test training and Loran-C familiarization, each test crew received a detailed pre-flight briefing. Once airborne, however, no further instructions or assistance were provided regarding Loran-C operation or mission performance unless the safety of flight was degraded as determined by the copilot. An on-board flight test engineer/observer was provided to document crew workload and performance as well as to monitor the airborne data acquisition system. When the subject pilot made a procedural error such as turning the wrong direction (horizontal steering error) or misinterpreting navigation information (disorientation), the observer documented the error. The flight continued to progress until the pilot or copilot recognized the error and corrected it or until a blunder occurred. (A blunder is defined as a procedural error which has gone unnoticed and resulted in the aircraft exceeding the normal airspace limits). The observer refrained from correcting the blunder error until in his judgement this course of action would result in significant loss of meaningful test data for this flight. (For example, blunders will not normally result in loss of accuracy data for more than one segment of a given route).

2.2 PURPOSE OF THE TESTS

Simply stated, the purposes of this operational test and evaluation encompassed three major areas. First demonstration of the degree of acceptability of the Loran-C navigator system for USCG operational missions. Second, compatibility in both the current VOR/DME NAS environment and the planned area navigation environment of the 1980's was to be assessed. Finally, the accuracy and repeatability of the Loran-C navigator for off-shore navigation was to be determined. Each of these major objectives is expanded and discussed in depth in Section 3.0.

2.3 ORGANIZATION OF THE REPORT

The results of the Loran-C flight test program are presented in the remainder of this report. Section 4.0 provides a detailed equipment summary, a flight test description, a review of test profile designs, data acquisition procedures and data reduction techniques. Section 5.0 presents and documents the specific results obtained in five major areas:

1. NAS/AC 90-45A Accuracy Analysis
2. SAR Operational Analysis
3. Surveillance/Oil Rig Analysis
4. Blunder/Workload Analysis
5. Operational Evaluation of the Prototype Loran-C Navigator

Section 6.0 extracts the primary results developed in each of these five major areas and summarizes the quantitative data. Section 7.0 presents the major qualitative conclusions as they relate to the stated program objectives from Section 3.0.

3.0

DETAILED TECHNICAL OBJECTIVES

The operational evaluation of the airborne Loran-C navigator system was designed to satisfy several general, or overall, objectives. These can be summarized as follows:

- 1) To obtain operational data on realistic Coast Guard Search and Rescue missions which can be used to determine the capabilities of the Loran-C system in relation to operational requirements and constraints.
- 2) To acquire accuracy data using the Loran-C navigator system which documents the absolute accuracy and the statistical error probability for use in Coast Guard surveillance and enforcement missions.
- 3) To evaluate the suitability of the Loran-C navigation system in the current VOR/DME NAS environment as well as the compatibility of Loran-C with the existing and planned NAS area navigation constraints.
- 4) To demonstrate the applicability of Loran-C navigation for use where VOR/DME coverage is inadequate, such as in off-shore helicopter operations.

In the process of developing a test plan suitable to achieve these desired overall objectives it was necessary to determine more specifically the Coast Guard goals, functional requirements, operational requirements and accuracy requirements. This determination evolved into a more detailed examination of the four major program objectives. For the operational suitability evaluation for both SAR and surveillance (objectives 1 and 2), it was decided that the suitability of the Loran-C system for use on the HH-52A helicopter was the primary specific objective. Suitability of the Loran-C system on other helicopters and subsequently on other aircraft can also be addressed from the data taken, but these issues are considered to be subordinate to the primary HH-52A operational suitability question. A fourth specific objective in the Coast Guard operational testing was to define a detailed list of functional and operational capabilities required of the Loran-C navigator by the Coast Guard. This list will be developed as a result of the data analysis and flight test observer logs acquired during the SAR and surveillance testing. Areas requiring upgrading will be isolated through designation of deficiencies noted in the prototype Loran-C system. Finally, the overall applicability of Loran-C for Coast Guard operations will be assessed as the fifth specific objective.

In the NAS testing, similar detailed test objectives also evolve. The primary question to be addressed is whether the Loran-C navigator can satisfy functional and accuracy requirements for NAS operations in the current air traffic control (ATC) environments for enroute, terminal and non-precision approach operations. The second specific NAS objective inherent in overall objective number (3) is "Can Loran-C meet the existing requirements for 2D RNAV systems not using VOR/DME for continuous navigation information?". These

requirements are currently specified in AC 90-45A and this evaluation will specifically address that document by developing a system level comparison to the stated requirements. The test data collected, test procedures, and data analysis are suitable for presentation to the FAA to determine the degree of compliance.

A final set of specific objectives results from analysis of general objective number (4). In order to acquire useful data applicable to the off-shore oil industry three test elements were defined. First, the problems of the industry must be analyzed. Preliminary review with helicopter operators has determined that finding and returning to an oil rig platform or an established drilling site is currently a problem due to inadequate VOR/DME coverage off-shore. In addition, a more accurate navigation system than currently provided by VOR/DME is required to safely locate the landing site during instrument flight conditions. This is due to the fact that VOR/DME navigation is limited by range and line of sight considerations. This translates into a Loran-C requirement for precise and reliable position information suitable for this application. Secondly, the requirements for statistical reliability of the accuracy data established the fact that a significant amount of overlap existed between surveillance and oil rig testing requirements. This produced a specific effort to integrate the test data acquisition as much as possible. Finally, the third test requirement which developed was the necessity to perform a minimum number of flights directly applicable to near shore oil industry operations. This was necessary to isolate any impact of Loran-C signal propagation discrepancies in the proximity of the coast line, where overland signal propagation characteristics might differ from overwater signal characteristics.

4.0

DESCRIPTION OF THE TESTS

Twenty-one flights were flown in the USCG Loran-C flight test program at Cape May, New Jersey during the testing period from 21 September 1976 to 19 October 1976. Of these twenty-one flights, five were shakedown, pilot orientation and Loran-C training; one was an aborted test flight as the result of an actual SAR mission; fifteen were for data collection purposes. Of these fifteen data flights, seven were for operational SAR missions including two flights in which conventional VOR/DME navigation techniques were used without the aid of the Loran-C navigator. In addition seven data flights were for a NAS compatibility evaluation and one flight was for surveillance test purposes. The total number of hours flown in the Loran-C test program was 51.7 hours. Table 4.1 presents a summary of the Loran-C flight test program including distribution of hours, test description and test sequence for the various tests flown by each of the subject pilots.

All SAR and surveillance flights were flown by updating the Loran-C navigator at the Cape May helipad prior to each flight (Section 4.1.2 describes the position update feature). All NAS flights were flown by simply inputting charted waypoint data using latitude and longitude without the helipad update. However, a special NAS flight was flown near the end of the test program (Flight No. 21) to obtain specific non-precision approach data in the updated latitude/longitude mode.

4.1 EQUIPMENT SUMMARY

The TDL-424 Loran Navigator tested was a prototype, miniaturized computer-controlled aircraft Loran navigation system (S/N 002) performing acquisition and track of Loran-C and D transmission and providing comprehensive navigational data as follows:

- Present position in lat/long or time differences
- Great circle range from present position to the selected "To" waypoint
- Bearing to the selected "To" waypoint
- Nine waypoint storage capability
- Desired track using two waypoints
- Actual track angle
- Desired track angle
- Track angle error
- Ground speed
- Cross track distance error

Table 4.1 Loran-C Flight Test Program Summary

FLIGHT NUMBER	DATE FLOWN	SUBJECT PILOTS						NUMBER OF FLIGHTS				NUMBER OF HOURS			
		A	B	C	D	E	F	FAM	SAR	NAS	SURV	FAM	SAR	NAS	SURV
1	9/21/76	P	C					1				2.6			
2	9/22/76					P	C	1				2.4			
3	9/23/76	P	C						1				2.0		
4	9/24/76					C	P	1				2.5			
5	9/24/76			C	P			1				2.3			
6	9/27/76	C	P						1				2.2		
7	9/28/76			P	C				1				2.0		
8	9/29/76			C	P				1				2.2		
9	10/ 6/76					P	C		1				2.8		
10	10/ 7/76	P	C						1				2.0		
11	10/12/76					C	P	1				2.4			
12	10/12/76	P	C							1				3.1	
13	10/13/76					P	C		1				1.7		
14	10/13/76					P	C			1				3.0	
15	10/14/76	C	P							1				3.0	
16	10/14/76					X	X				1				2.6
17	10/15/76					P	C			1				3.0	
18*	10/15/76	C				P					1 (abort)				1.2
19	10/18/76					C	P			1				2.8	
20	10/18/76			C	P					1				2.7	
21	10/19/76	X	X							1				3.2	
Subtotals								5	7	7	2	12.2	14.9	20.8	3.8
TOTALS								21				51.7			

/NOTE/ P = Designated pilot for this flight.
 C = Designated co-pilot for this flight.
 X = Subject pilots on this flight shared pilot/copilot duties
 by switching control at the pre-designated point in-flight.
 *Surveillance flight was aborted shortly after take-off
 due to an actual SAR mission.

- Steering outputs available for Loran deviation indicator, course deviation indicator, and autopilot
- Time-to-go to selected waypoint

Additional features include:

- Position updating
- Data link
- Automatic Loran secondary station selection, waypoint and leg change
- Magnetic variation entry

The TDL-424 Loran navigator provided complete navigation capability from both functional and accuracy viewpoints. However, the prototype nature of this unit was not intended to represent the final pre-production design. Rather, an important part of the evaluation was to obtain flight crew, observer and USCG feedback regarding design modifications affecting crew workload, functional acceptability and automation of various procedures.

All operator controls and indicators are located on the TDL-424 front panel shown in Figure 4.1. Detailed explanations of switch, indicator, and display functions are contained in Reference 6. Use of these functions in actual operating procedures is described in Sections IV, V and VI of the reference.

4.1.2 The TDL-424 Navigator System

The TDL-424 is comprised of a Loran receiver, a high-speed digital computer and a unique program intelligence that makes the machine a navigation system. How time difference mapping is converted into lat/long mapping is shown in Figure 4.2 which is a simplified functional diagram of the software being used.

Received Loran signals are processed under software control to produce the two basic time differences, TDA and TDB. These represent present position time differences. The coordinate converter position of the program performs calculations required to convert these into lat/longs. The coordinate converter performs the same function for waypoint TDs input from the panel.

The lat/longs can be corrected for propagation anomalies by position updating and displayed as required. This procedure is normally used during system initialization by entering a known value of aircraft lat/long position, for example, the ramp location or the end of the runway. The position update procedure is accomplished by entering the known position in either lat/long or time difference coordinates as follows:

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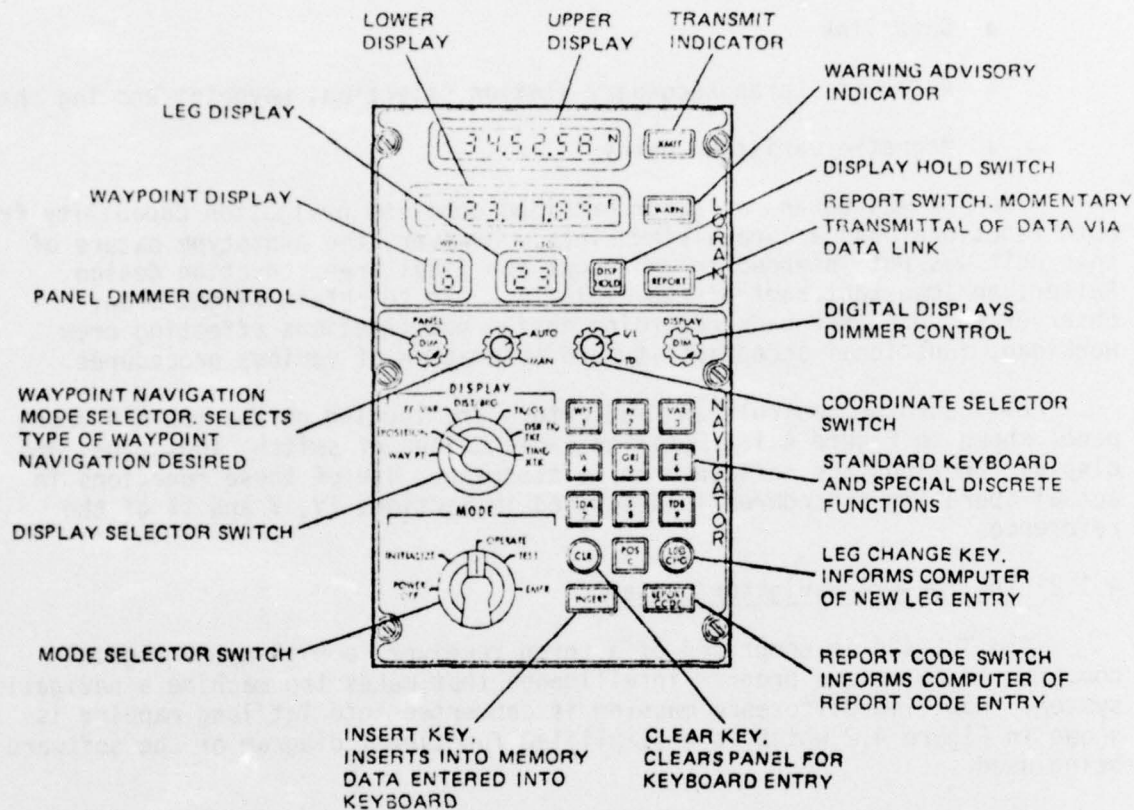
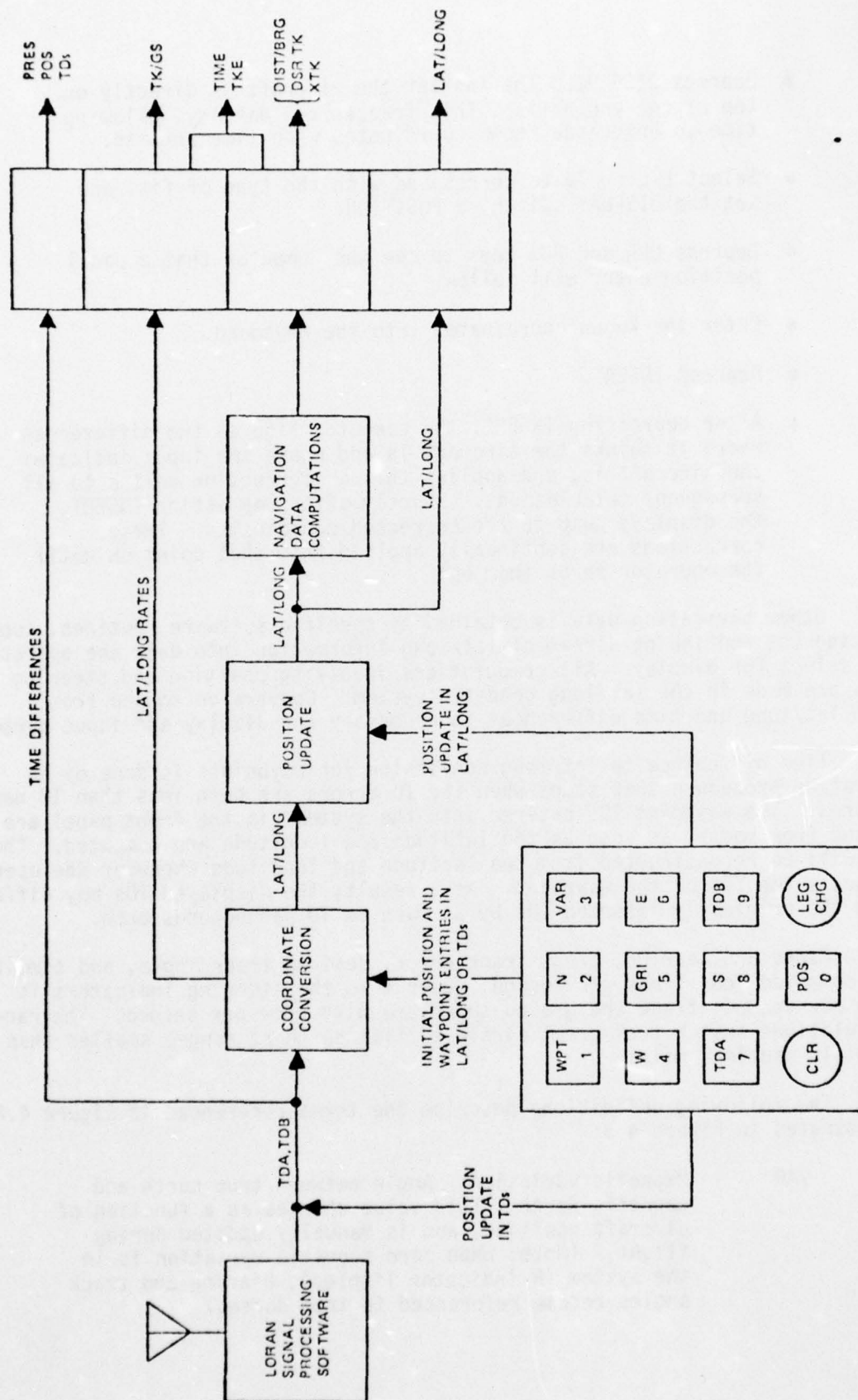


Figure 4.1 TDL-424 Front Panel Display

Figure 4.2 TDL-424 Block Design



- Depress DISP HOLD the instant the aircraft is directly on top of the known fix. This freezes the display, allowing time to enter the known coordinates when time permits.
- Select L/L or TD to correspond with the type of fix, and set the DISPLAY switch to POSITION.
- Depress CLR and POS keys to cue the computer that a panel position entry will follow.
- Enter the known coordinates into the keyboard.
- Depress INSERT.
- After depressing INSERT, the computer figures the differences where it thinks the aircraft is and where the input indicates the aircraft is, and applies this as correction deltas to all subsequent calculations. Shortly after depressing INSERT, the displays jump to the corrected coordinates. These corrections are continually applied from that point on until the operator zeros them out.

Other navigation data is obtained by specific software routines, converting the continuing stream of lat/long information into data the operator may select for display. All computations involving position and steering data are made in the lat/long geodetic system. Conversion to and from both lat/long and time differences is necessary for display and input purposes.

Time difference to lat/long conversion for waypoints is done by an iterative procedure that stops when the TD errors are both less than 10 nanoseconds. The waypoint TDs entered into the system via the front panel are erased from memory as soon as the latitude and longitude are computed. The TDs will be reconstructed from the latitude and longitude whenever the operator requests the TDs of the waypoint. As a result, the displayed TDs may differ from the originally inserted TDs by as much as 10 nanoseconds each.

Range and bearing, cross track error, desired track angle, and time-to-go are computed four times per second. Output to the steering indicators is once per second; track and ground speed are also once per second. The range calculations switch from great circle to flat earth at ranges smaller than about 10 nautical miles.

The following definitions describe the terms referenced in Figure 4.2 and illustrated in Figure 4.3:

- VAR - Magnetic variation. Angle between true north and magnetic north. This value changes as a function of aircraft position, and is manually updated during flight. (Note: When zero magnetic variation is in the system (N indicator lighted), bearing and track angles become referenced to true north.)

TIME - Estimated time to go to selected T0 waypoint.

/Note/ Three displayed functions - track angle, track angle error, and time-to-go to selected T0 waypoint - are functions of velocity that become unstable when the velocity is small. Below 32 knots the display of these functions is inhibited. Navigating beyond the latitude range of 80°S to 80°N can cause numerical overflows in the navigation computations due to meridian convergence.

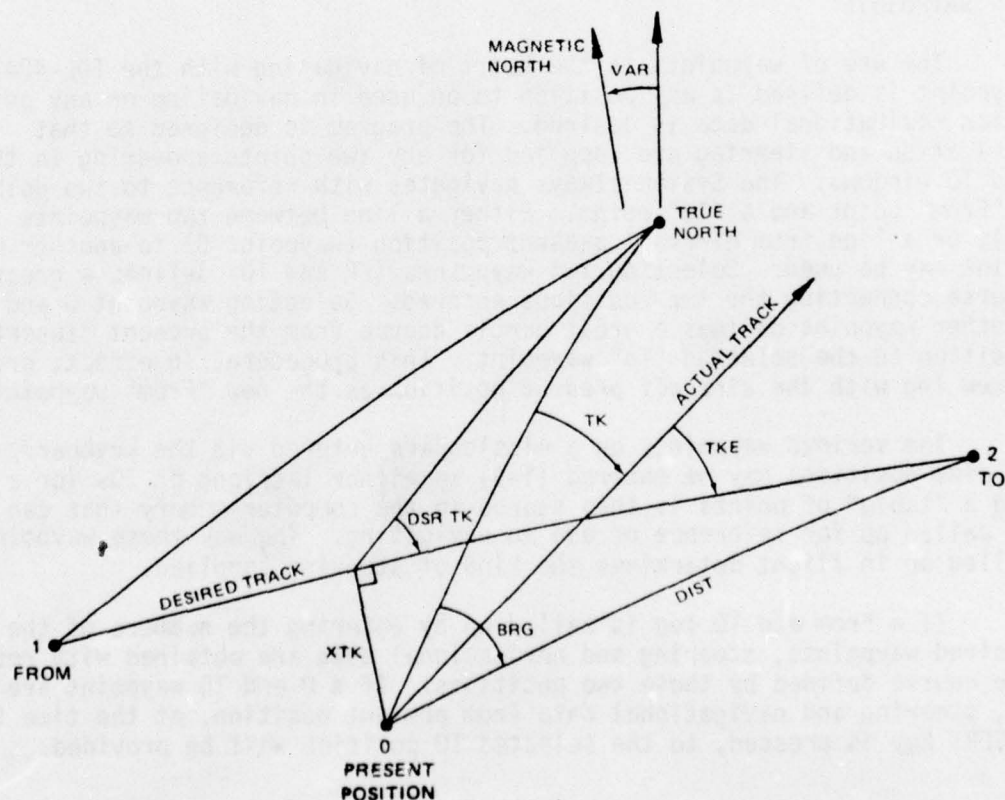


Figure 4.3 The TDL-424 Navigation Coordinate System

- DIST - Distance. Great circle range from present position to T0 waypoint.
- BRG - Bearing. Angle between true north and a line from present position to T0 waypoint.
- TK - Track Angle. Angle between true (or magnetic) north and actual ground track.
- GS - Average Ground Speed. Rate of aircraft travel, computed by differentiating lat/long positions once per second.
- DSR TK - Desired Track Angle. Angle between true or magnetic north and desired track.
- TKE - Track Angle Error. Angle between actual track and desired track.
- XTK - Cross Track Distance (error). Left or right of present position from desired track, measured on a line perpendicular to desired track.

4.1.3 TDL-424 Navigation Techniques

A. WAYPOINTS

The use of waypoints is the heart of navigating with the TDL-424. A waypoint is defined as any position to be used in navigating or any point for which navigational data is desired. The program is designed so that navigation and steering are supplied for any two points appearing in the FR and T0 windows. The System always navigates with reference to two points — a "From" point and a "To" point. Either a line between two waypoints (FR and T0), or a line from aircraft present position (waypoint 0) to another waypoint may be used. Selecting two waypoints (FR and T0) defines a great circle course connecting the two positions entered. Selecting waypoint 0 and another waypoint defines a great circle course from the present "Insert" position to the selected "To" waypoint. This procedure, in effect, creates a new leg with the aircraft present position as the new "From" waypoint.

The various waypoints on a mission are entered via the keyboard. Up to nine positions may be entered (1-9) in either lat/long or TDs (or a mix) and a "table" of points is then stored in the computer memory that can later be called up for reference or use in navigating. The way these waypoints are called up in flight determines the kind of steering supplied.

If a From and T0 leg is called up by entering the numbers of the two desired waypoints, steering and navigational data are obtained with respect to the course defined by those two positions. If a 0 and T0 waypoint are called up, steering and navigational data from present position, at the time the INSERT key is pressed, to the selected T0 position will be provided.

The TDL-424 provides the alternatives of automatic or manual waypoint selection. In AUTO mode, the program sequences legs automatically, selecting the next leg in numerical sequence as the aircraft arrives at a waypoint destination. In the MANUAL mode, the operator must make the selection of the next leg. Each leg must be called up when needed, and navigation/steering information is with respect to that leg until a manual "LEG CHANGE" and "INSERT" operation is performed. This is true even if the aircraft has arrived at or passed a waypoint.

Loran time difference navigation has been demonstrated to be a system of navigation with a high degree of repeatability. Time differences are directly relatable to position for a specified Loran chain, and it is possible to return to a position based on a time difference fix without the use of charts or other data. The TDL-424 makes practical use of this principle by allowing waypoints to be entered in time differences as well as lat/long.

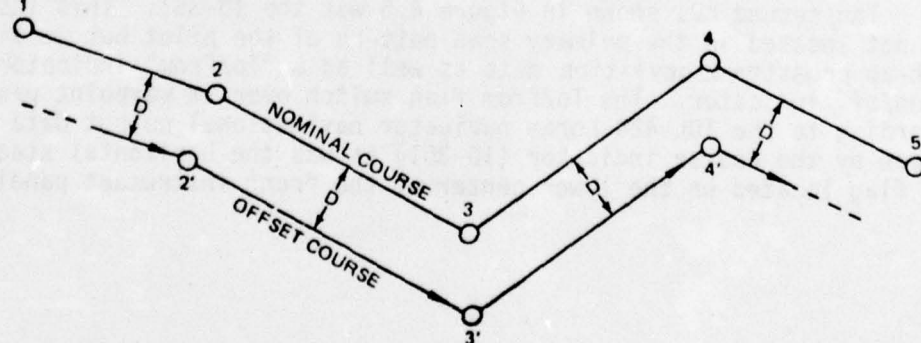
B. PARALLEL TRACK STEERING

The parallel track steering feature is designed for a special mission, such as airways offset track flying or search and rescue missions. Parallel track steering provides the ability to fly along a course parallel to a given course at a selectable distance from it. The offset distance can vary from .1 to 30 nautical miles. A series of such offset legs may be flown corresponding to as many From and TO legs as are entered in the system (nine maximum). Also, the offset distance can be changed in mid-leg.

The TDL-424 program provides this capability by projecting an artificial destination based on the nominal course coordinates and the offset distance entered. As indicated in Figure 4.4, in order for the program to derive the artificial destination 3', it needs the coordinates of waypoints 2, 3 and 4 plus the offset distance, D.

Once the offset has been entered, all steering and other nav data are with reference to the artificial destination. The original waypoint-defined course is not lost, however; it is held in memory until the parallel track steering command is cancelled by entering zero offset distance.

Figure 4.4 Loran-C Parallel Track Illustration



A subtle TDL-424 system characteristic develops when flying in the parallel track steering mode. This characteristic is dependent upon whether auto or manual waypoint selection is chosen. In the auto mode, the TDL-424 performs the necessary trigonometry to determine the angle bisector between the inbound and outbound legs of the active "To" waypoint. The automatic leg switching then occurs with respect to the waypoint displaced along the angle bisector a distance equal to the parallel track offset.

In the manual waypoint selection mode of operation, the TDL-424 does not have any information stored regarding the outbound course from the active "To" waypoint. Consequently, the software is set up to indicate arrival at the waypoint based on an orthogonal projection of the waypoint a distance equal to the parallel track offset.

This subtlety leads to differences in aircraft track made good which must be kept in mind by the flight crew especially in terminal area and final approach operation in the parallel track steering mode.

4.1.4 TDL-424 Display Interface

Navigational data derived from the TDL-424 Loran navigator which is continuously displayed to the pilot includes cross track deviation error (CDI) and To/From flag switch-over at waypoint passage. In the flight test installation the cross track deviation error was displayed on the Navigation Flight Director Indicator (NFDI, Figure 4.5) which was located in the center of the pilot's instrument panel. Two different CDI sensitivities were available to the pilot by the selection of a two position switch. One position allowed a full scale CDI needle deflection of ± 2.5 nm, the other ± 0.5 nm. The ± 0.5 nm scale sensitivity position was the one utilized throughout the Loran-C flight test program.

There were two CDIs available in the cockpit during the flight test program. The primary instrument used by the pilot during the testing was the NFDI shown in the upper right hand corner of Figure 4.5. This instrument displayed crosstrack deviation and an integral on/off indicator. The NFDI has 4 dots on either side of the center dot (0.0 nm error). Consequently, the ± 0.5 nm sensitivity position gave the pilot the CDI needle deflection of ± 0.125 nm per dot.

The second CDI shown in Figure 4.5 was the ID-351. This instrument was not located in the primary scan pattern of the pilot but it did provide back-up crosstrack deviation data as well as a "To/From" indicator flag and an on/off indicator. The To/From flag switch over at waypoint passage according to the TDL-424 Loran navigator navigational output data was driven by the course indicator (ID-351) as was the horizontal steering needle off flag located on the lower center of the front instrument panel (Figure 4.5).

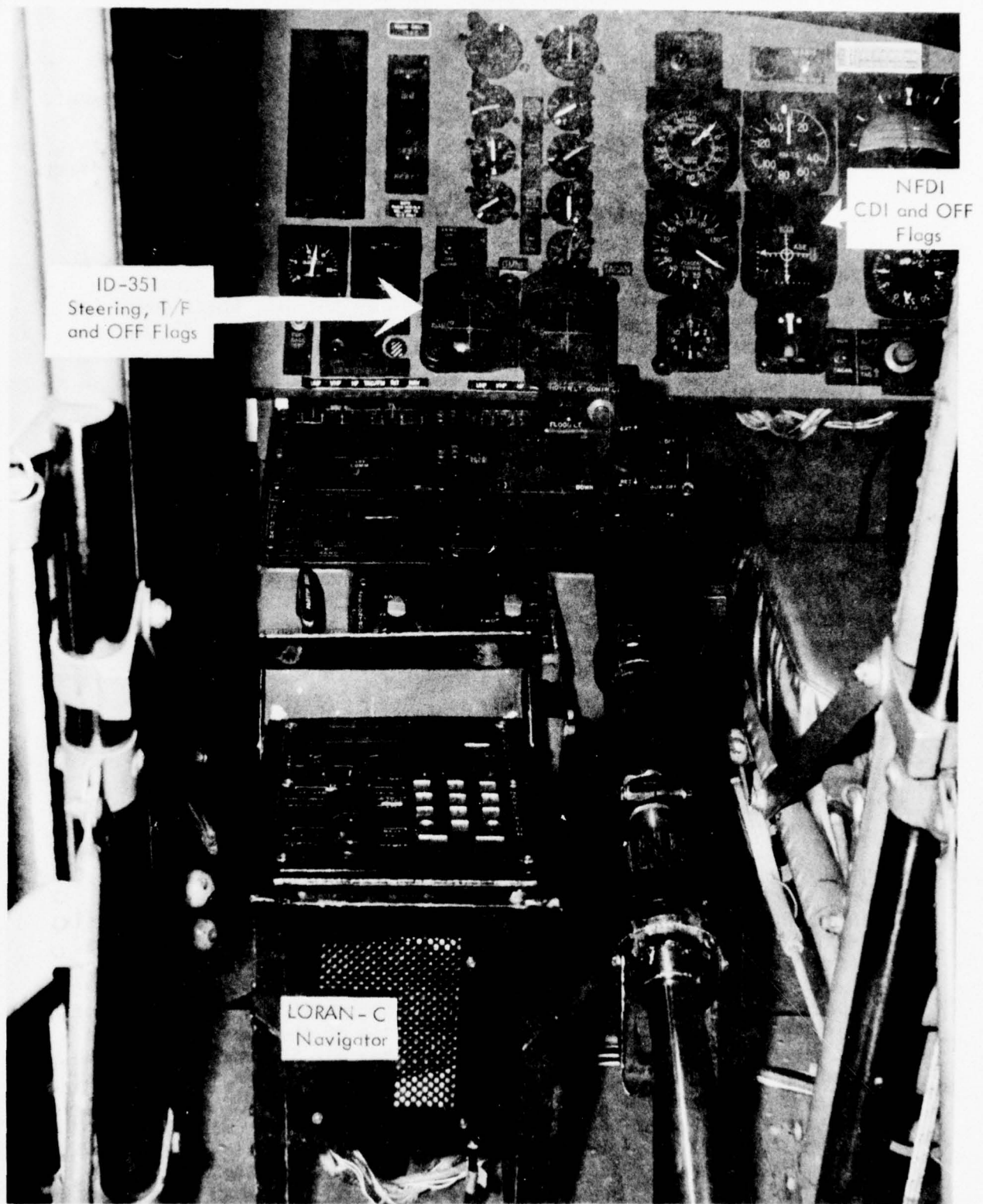


Figure 4.5 Loran-C Navigator/Display Location in the HH-52A Test Aircraft

4.1.5 Loran-C Chain Utilized

Throughout the Loran-C flight test program the signals from three Loran-C transmitters were used. These transmitters were the master station located at Cape Fear, North Carolina, a secondary station at Nantucket, Massachusetts and a second secondary station at Dana, Indiana.

4.1.6 Flight Test Helicopter

The aircraft utilized for the Loran-C flight test program was a USCG HH-52A helicopter (S/N 1385). This type of aircraft normally cruises at 80 kts and it is primarily used by the U.S. Coast Guard for Search and Rescue Operations. The test aircraft was based at the USCG Air Station, Cape May, New Jersey.

4.2 TEST PROFILES

The USCG Loran-C flight test program consisted of flying simulated operational Coast Guard missions. In addition, the testing included an evaluation of the compatibility of the Loran-C navigator system to the National Airspace System (NAS) environment. The NAS testing consisted of flying enroute, transition, and terminal maneuvering route segments, and non-precision approaches in the National Aviation Facilities Experimental Center (NAFEC) terminal area. Subsections 4.2.1, 4.2.2 and 4.2.3, present a detailed description of flight profiles, pattern definition, and test scenarios for the SAR, Surveillance, and NAS testing, respectively. These profiles were developed by Systems Control, Inc. (Vt) for the Coast Guard as a part of the flight test planning effort.

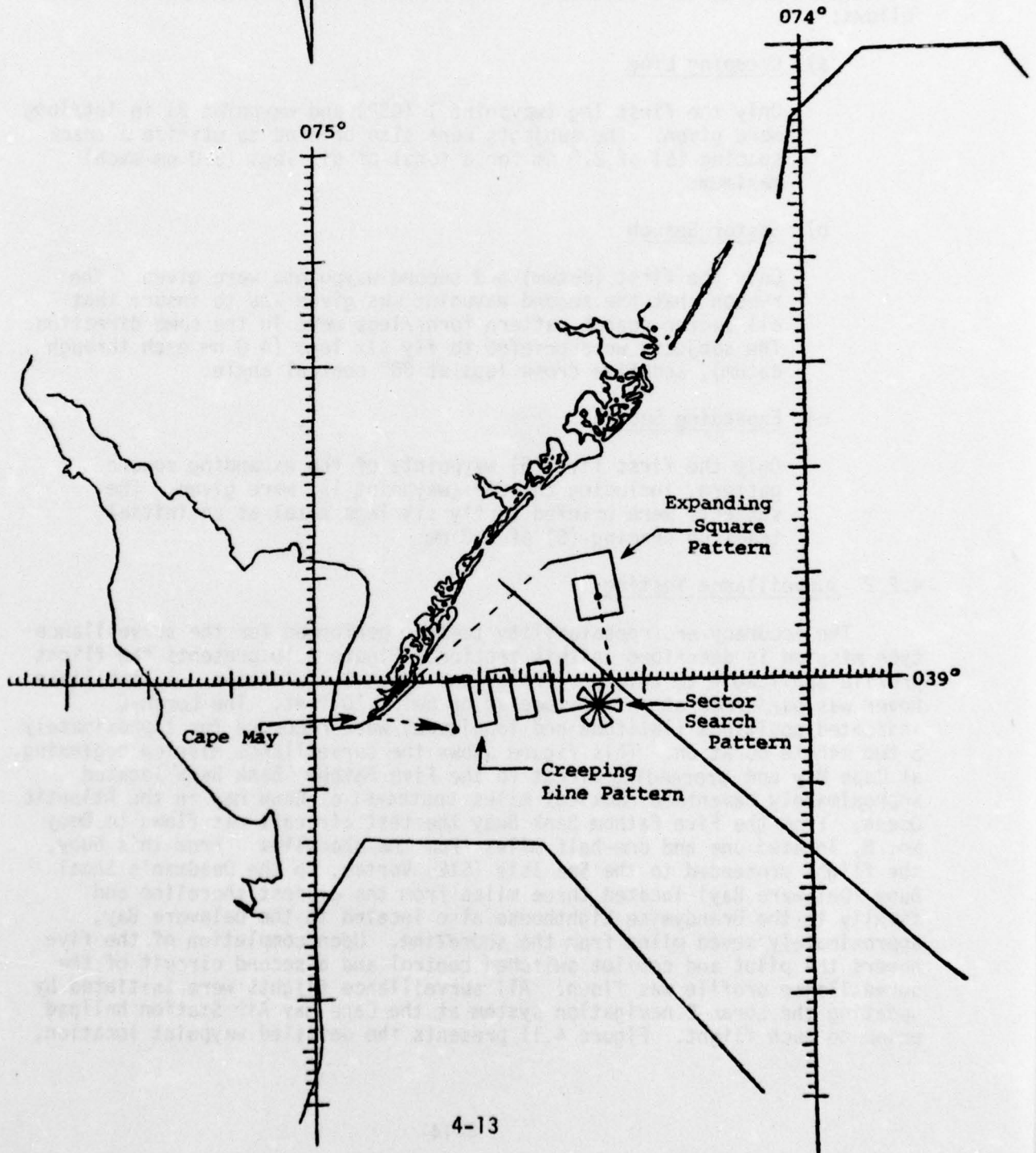
4.2.1 Operational SAR Missions

The three test profiles flown during the operational search and rescue testing are illustrated in Figure 4.6. This figure shows the mission beginning at Cape May Air Station and proceeding enroute to the Commence Search Point (CSP). Upon reaching the CSP, the test helicopter immediately initiated a creeping line search pattern of a fifty square mile area, utilizing a track spacing of 2.0 nm and a leg length of 5.0 nm. Upon completion of six legs of the creeping line search the aircraft initiated a sector search. This sector search pattern consisted of six legs and five cross legs with an angle between legs of thirty degrees. After the last leg of the sector search had been flown the aircraft proceeded direct to the CSP of the expanding square search pattern. The expanding square pattern consisted of six legs with a track spacing of two miles. At the conclusion of the last leg of the expanding square the aircraft proceeded direct to the Cape May Air Station waypoint (helipad) at which time the flight terminated. As previously discussed, all SAR patterns were executed after updating the Loran-C navigation system at the Cape May Air Station helipad prior to each flight. General characteristics of the SAR operational testing included a total track length of approximately 140 nm flown at an indicated airspeed of 75 to 80 KTS and an altitude of 2500 feet. This altitude was required to satisfy tracking radar requirements.



Figure 4.6 SAR Flight Test Profile

--- Enroute Segment
 — SAR Desired Profile



Figures 4.7, 4.8 and 4.9 present detailed waypoint location information for each of the creeping line, sector, and expanding square search patterns respectively. Waypoint location in latitude and longitude coordinates, both true and magnetic courses, and along track distance is shown for each route segment.

During the pre-flight briefing preceding each SAR operational test, the subject pilots were instructed to fly each respective SAR pattern as follows:

a) Creeping Line

Only the first leg (waypoint 1 (CSP) and waypoint 2) in lat/long were given. The subjects were also briefed to utilize a track spacing (S) of 2.0 nm for a total of six legs (5.0 nm each) maximum.

b) Sector Search

Only the first (datum) and second waypoints were given. The reason that the second waypoint was given was to insure that all sector search pattern turns/legs were in the same direction. The subjects were briefed to fly six legs (4.0 nm each through datum), and five cross legs at 30° central angle.

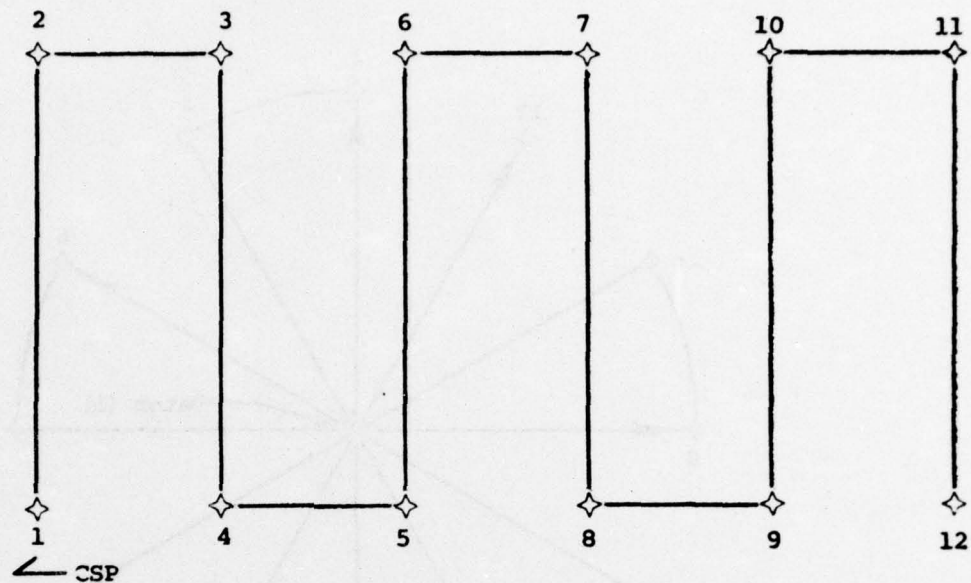
c) Expanding Square

Only the first five (5) waypoints of the expanding square pattern, including the CSP (waypoint 1), were given. The subjects were briefed to fly six legs total at an initial tracking spacing (S) of 2.0 nm.

4.2.2 Surveillance Testing

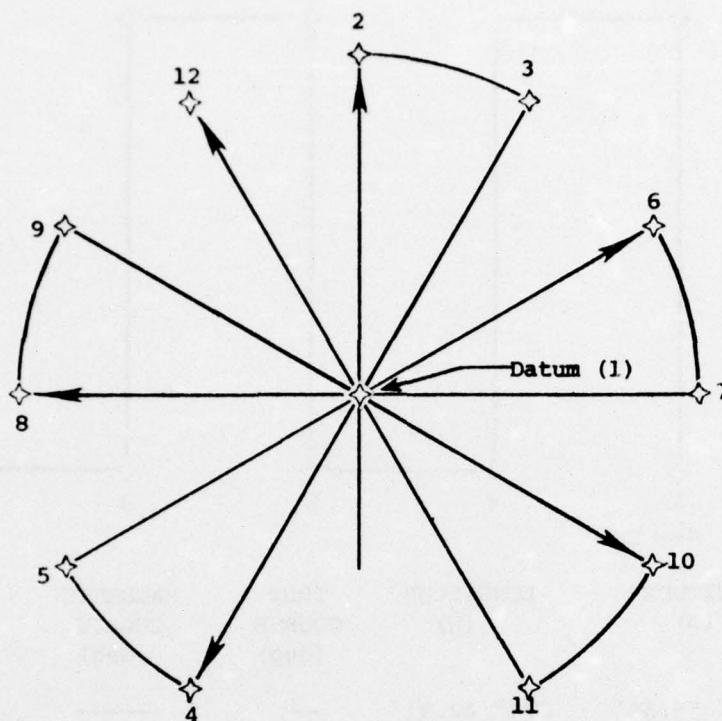
The accuracy and repeatability testing performed for the surveillance type mission is described in this section. Figure 4.10 presents the flight profile applicable to this portion of the Loran-C evaluation. A stabilized hover was performed at an altitude at or below 70 feet. The Loran-C indicated positions (latitude and longitude) were recorded for approximately a two minute duration. This figure shows the surveillance mission beginning at Cape May and proceeding direct to the Five Fathom Bank Buoy located approximately seventeen nautical miles southeast of Cape May in the Atlantic Ocean. From the Five Fathom Bank Buoy the test aircraft was flown to Buoy No. 8, located one and one-half miles from the shoreline. From this buoy, the flight proceeded to the Sea Isle (SIE) Vortac, to the Deadman's Shoal Buoy (Delaware Bay) located three miles from the closest shoreline and finally to the Brandywine Lighthouse also located in the Delaware Bay, approximately seven miles from the shoreline. Upon completion of the five hovers the pilot and copilot switched control and a second circuit of the surveillance profile was flown. All surveillance flights were initiated by updating the Loran-C navigation system at the Cape May Air Station helipad prior to each flight. Figure 4.11 presents the detailed waypoint location,

Figure 4.7 SAR Creeping Line Pattern Definition



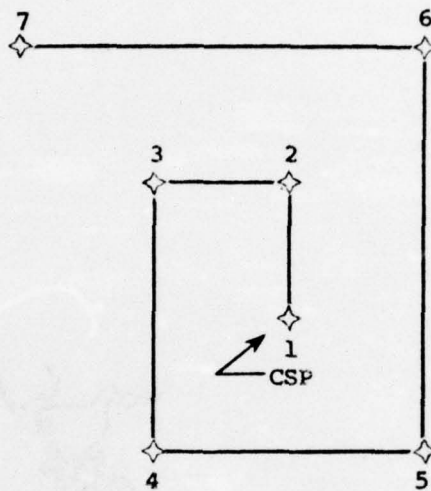
WAYPOINT	LATITUDE (N)	LONGITUDE (W)	TRUE COURSE (deg)	MAGNETIC COURSE (deg)	ALONGTRACK DISTANCE (nm)
1 (CSP)	038° 55.30'	074° 42.91'	—	—	—
2	039° 00.21'	074° 44.03'	350	0,360	5.0
3	039° 00.56'	074° 41.50'	080	090	2.0
4	038° 55.65'	074° 40.38'	170	180	5.0
5	038° 56.00'	074° 37.86'	080	090	2.0
6	039° 00.91'	074° 38.98'	350	0,360	5.0
7	039° 01.25'	074° 36.45'	080	090	2.0
8	038° 56.33'	074° 35.33'	170	180	5.0
9	038° 56.68'	074° 32.81'	080	090	2.0
10	039° 01.60'	074° 33.93'	350	0,360	5.0
11	039° 01.95'	074° 31.40'	080	090	2.0
12	038° 57.01'	074° 30.28'	170	180	5.0

Figure 4.8 SAR Sector Search Pattern Definition



WAYPOINT	LATITUDE (N)	LONGITUDE (W)	TRUE COURSE (deg)	MAGNETIC COURSE (deg)	ALONGTRACK DISTANCE (nm)
1	038° 57.70'	074° 25.23'	—	—	—
2	038° 58.05'	074° 22.71'	080	090	2.0
3	038° 57.01'	074° 22.83'	185	195	1.0
4	038° 58.38'	074° 27.63'	290	300	4.0
5	038° 59.23'	074° 26.88'	034	044	1.0
6	038° 56.16'	074° 23.58'	140	150	4.0
7	038° 55.73'	074° 24.78'	245	255	1.0
8	038° 59.66'	074° 25.68'	350	0,360	4.0
9	038° 59.58'	074° 24.35'	095	105	1.0
10	038° 55.81'	074° 26.10'	200	210	4.0
11	038° 56.41'	074° 27.18'	305	315	1.0
12	038° 58.98'	074° 23.26'	050	060	4.0

Figure 4.9 SAR Expanding Square Pattern Definition



WAYPOINT	LATITUDE (N)	LONGITUDE (W)	TRUE COURSE (deg)	MAGNETIC COURSE (deg)	ALONGTRACK DISTANCE (nm)
1 (CSP)	039° 07.85'	074° 25.28'	—	—	—
2	039° 09.81'	074° 25.73'	350	0,360	2.0
3	039° 09.46'	074° 28.26'	260	270	2.0
4	039° 05.51'	074° 27.36'	170	180	4.0
5	039° 06.20'	074° 22.28'	080	090	4.0
6	039° 12.10'	074° 23.63	350	0,360	6.0
7	039° 11.05'	074° 31.25'	260	270	6.0

Figure 4.10
Surveillance/Oil Rig Flight Test Profile

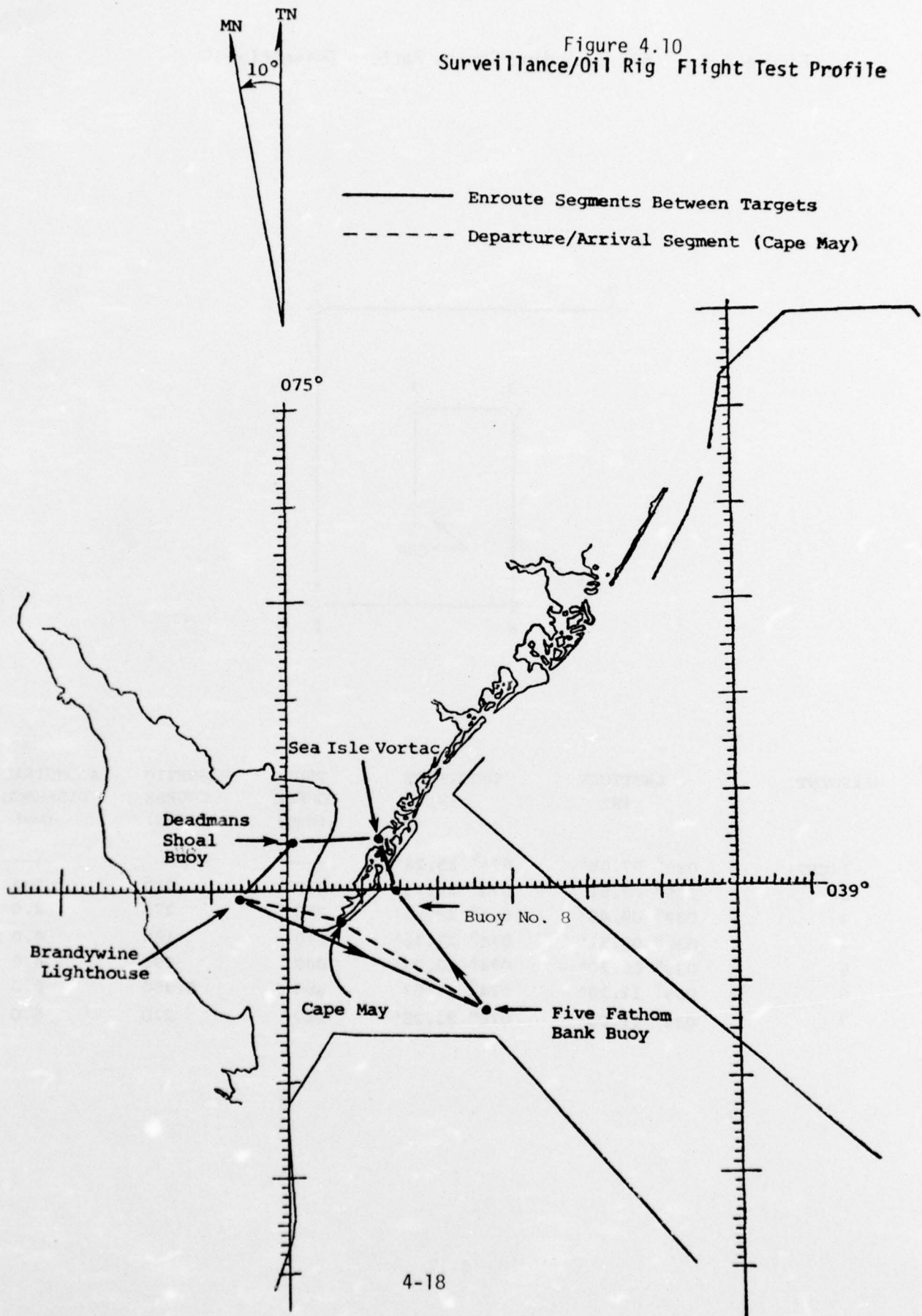
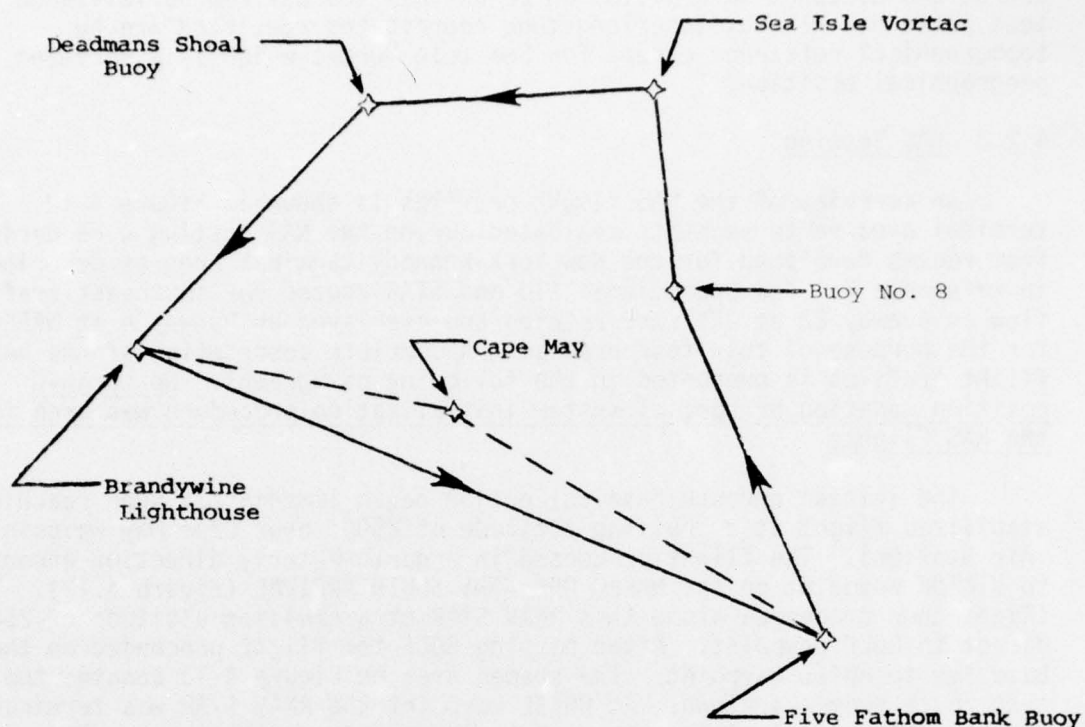


Figure 4.11 Surveillance Test Pattern Definition



WAYPOINT	LATITUDE (n)	LONGITUDE (w)	TRUE COURSE (deg)	MAGNETIC COURSE (deg)	ALONGTRACK DISTANCE (nm)
Cape May	038° 56.63'	074° 52.95'			
Five Fathom Bank Buoy	038° 47.3'	074° 34.6'	123.2	133.2	17
Buoy No. 8	038° 59.8'	074° 45.5'	324.9	334.9	15
Sea Isle Vortac	039° 05.7'	074° 48.0'	344.5	354.5	6
Deadmans Shoal Buoy	039° 05.2'	074° 59.9'	266.9	276.9	9
Brandywine Lighthouse	038° 59.2'	075° 06.8'	221.8	231.8	8
Five Fathom Bank Buoy	(same as above)		115.2	125.2	27
or					
Cape May	(same as above)		103.0	113.0	11

course and distance information which defines the desired surveillance test pattern. All latitude/longitude coordinates specified are by topographical reference except for Sea Isle Vortac which is a surveyed geographical position.

4.2.3 NAS Testing

An overview of the NAS flight profiles is shown in Figure 4.12. The terminal area route segments evaluated during the NAS testing were derived from routes developed for the New York-Kennedy terminal area as described in Reference 1. The operational SID and STAR routes for southeast traffic flow on Runway 22 at JFK were rotated and overlayed on Runway 4 at NAFEC for the purpose of this test program. A complete description of the NAS flight profiles is presented in the following paragraphs. No Loran-C position updating or special system initialization procedure was used for the NAS Flights.

The initial enroute data collection began immediately upon reaching stabilized flight at a cruising altitude of 2500' over Cape May waypoint (Air Station). The flight proceeded in a northwesterly direction enroute to VICTOR waypoint on the NAFEC ONE RNAV SOUTH ARRIVAL (Figure 4.13). The flight then proceeded along this RNAV STAR at a cruising altitude of 2500' direct to GOLF waypoint. After passing GOLF the flight proceeded on the base leg to HOTEL waypoint. The shaded area on Figure 4.13 denotes the test route segments flown. At HOTEL waypoint the RNAV STAR was terminated and the RNAV non-precision approach to Runway 04 was initiated. The appropriate approach plate is given in Figure 4.14. After passing HOTEL waypoint the flight proceeded to INDIA waypoint, establishing a procedural descent as necessary to cross INDIA at 1500'. After passing INDIA, the procedural descent continued to the Minimum Descent Altitude (MDA) of 520' at the Missed Approach Waypoint (MAP) located on the threshold of Runway 04 at which time the approach was terminated and a landing at NAFEC was accomplished. The aircraft was then refueled and calibration of the C-band beacon for EAIR tracking radar was completed before the next departure.

Departure from NAFEC was accomplished using the ATLANTIC CITY ONE RNAV SOUTH DEPARTURE shown in Figure 4.15 (shaded areas). Takeoff from ACY was followed by a climb outbound direct to BRAVO waypoint. From BRAVO waypoint, the SID continued direct to ROMEO waypoint. The departure then turned southbound and proceeded direct to SIERRA waypoint. The final route segment of the SID turned the aircraft westbound direct to VICTOR waypoint at which point the second RNAV STAR of the NAS testing sequence was initiated. This STAR proceeded from VICTOR to GOLF waypoints similar to the first STAR. However, prior to reaching GOLF waypoint, the subject pilot was given one of the following impromptu changes:

"Offset Base Leg 3.0 Miles Right and Proceed to Intercept the Final Approach Course"

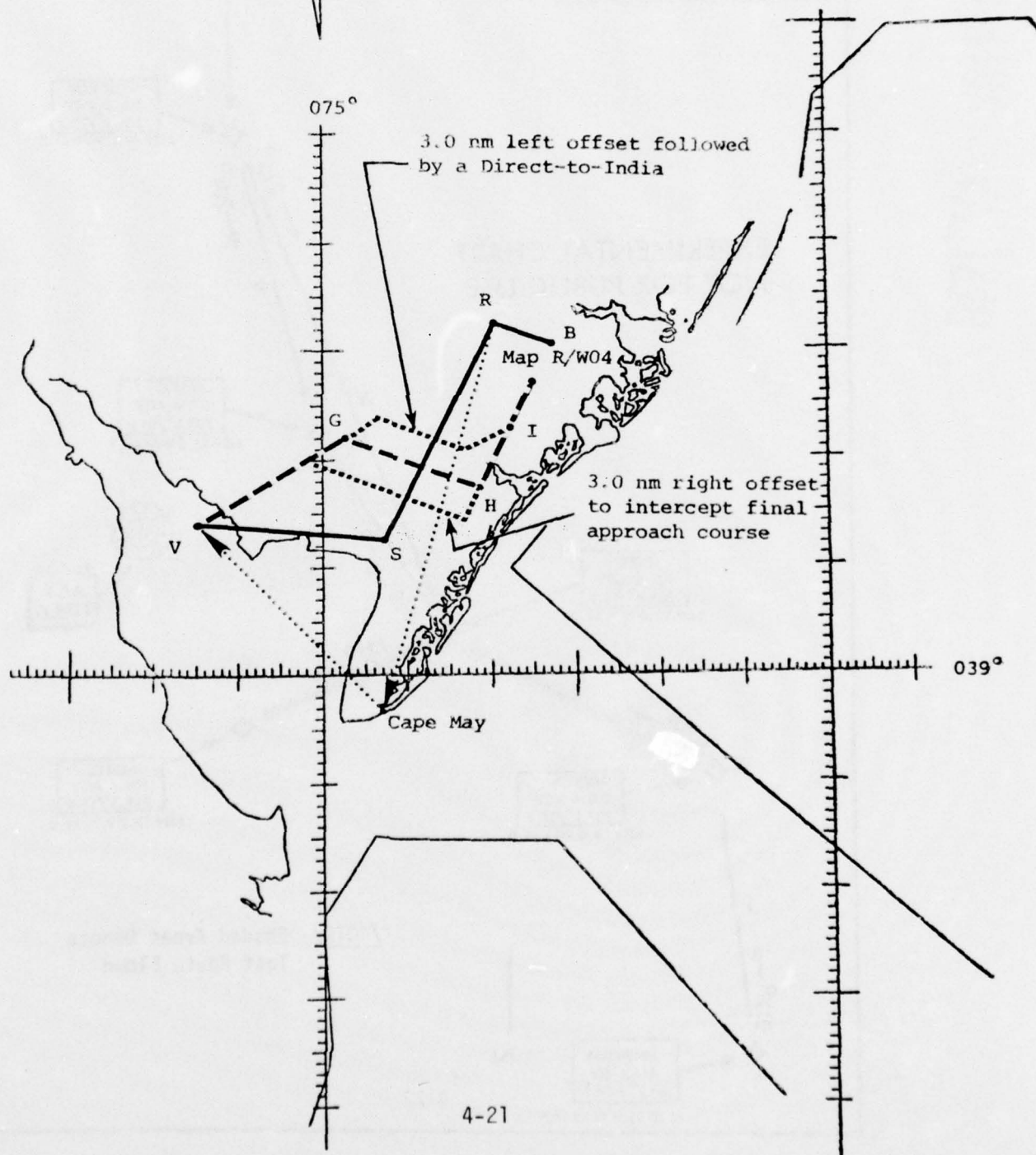
or

"Maintain Present Heading Past GOLF Waypoint to Intercept a 3.0 Mile Left Offset on Base Leg"



Figure 4.12 NAS Flight Test Profiles

- Enroute Segments
- NAFEC ONE RNAV ARRIVAL (STAR)
- ATLANTIC CITY ONE RNAV DEPARTURE (SID)
- Desired Impromptu Route



ATLANTIC CITY, N.J. STAR NAFEC ATLANTIC CITY

NAFEC ONE RNAV ARRIVAL

Figure 4.13

NORTH ARRIVAL

Rwy 4: Echo W/P, direct Foxtrot W/P, direct Golf W/P, direct Hotel W/P. Cross Foxtrot W/P at 2500', cross Golf W/P at 2500', cross Hotel W/P at 2500'.

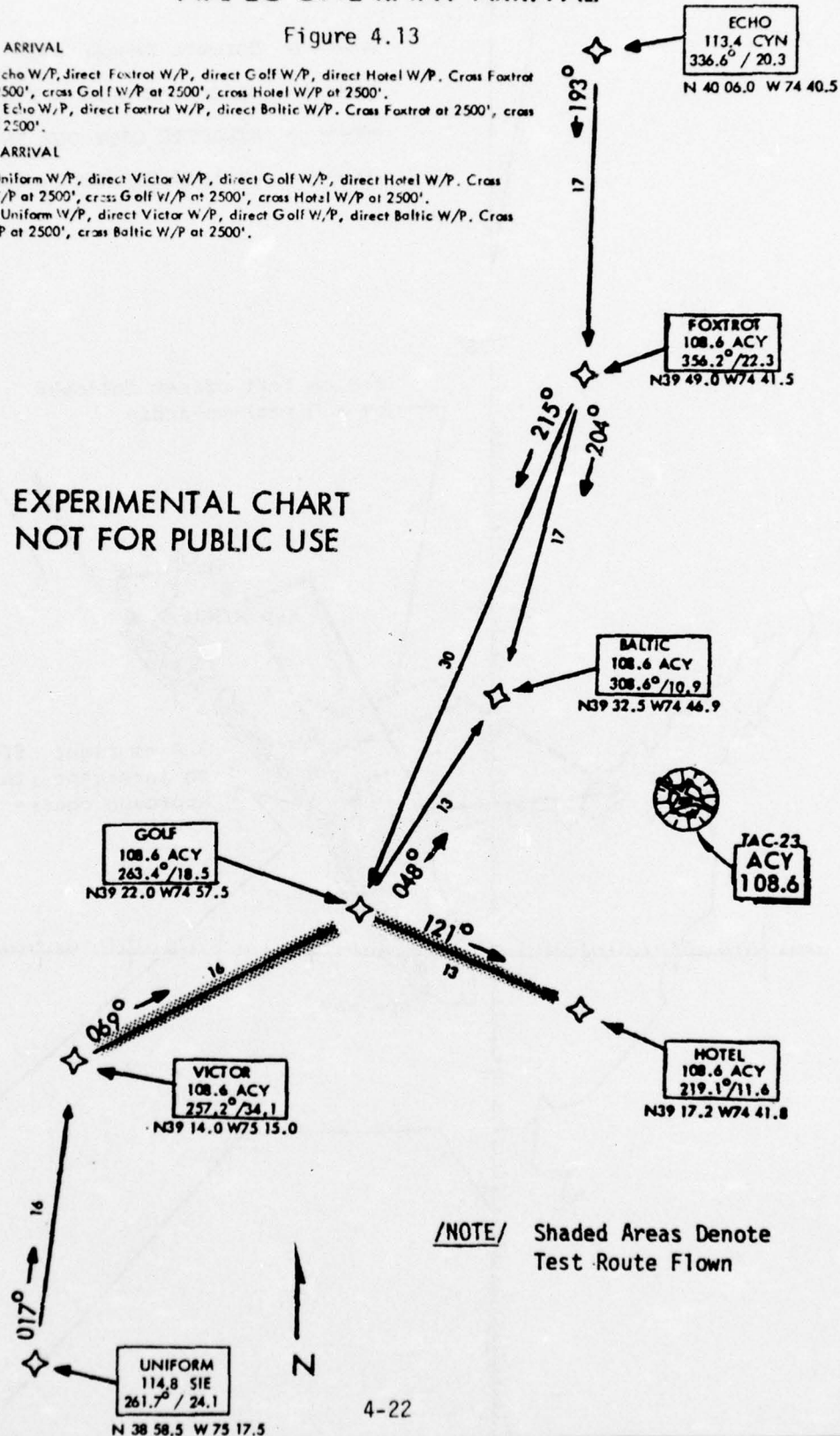
Rwy 13: Echo W/P, direct Foxtrot W/P, direct Baltic W/P. Cross Foxtrot at 2500', cross Baltic at 2500'.

SOUTH ARRIVAL

Rwy 4: Uniform W/P, direct Victor W/P, direct Golf W/P, direct Hotel W/P. Cross Victor W/P at 2500', cross Golf W/P at 2500', cross Hotel W/P at 2500'.

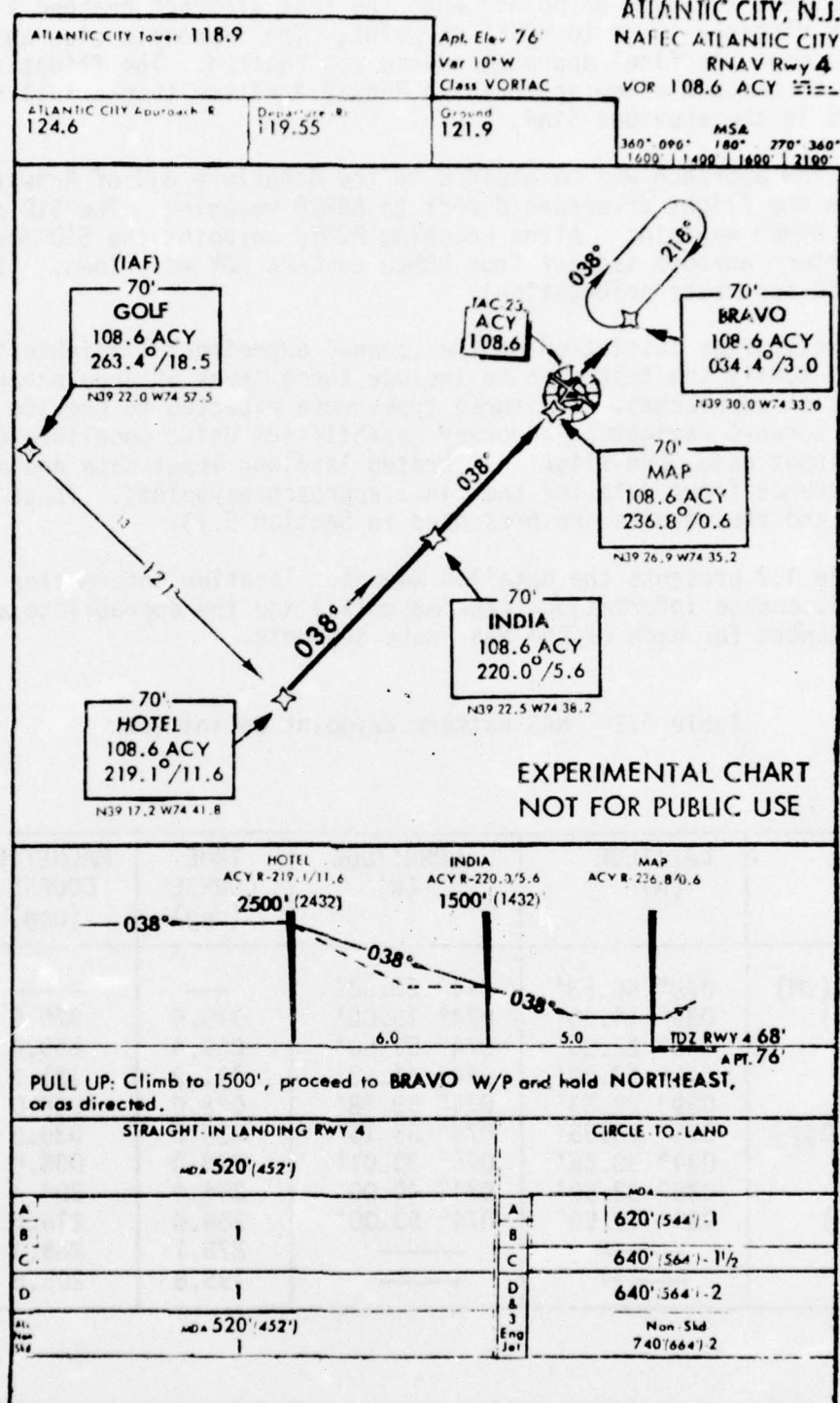
Rwy 13: Uniform W/P, direct Victor W/P, direct Golf W/P, direct Baltic W/P. Cross Golf W/P at 2500', cross Baltic W/P at 2500'.

EXPERIMENTAL CHART
NOT FOR PUBLIC USE



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Figure 4.14 Approach Plate to NAFEC R/W 04



The latter impromptu clearance was terminated with an instruction to "Proceed Direct To INDIA Waypoint" when the test aircraft reached a point four miles distance-to-go to HOTEL waypoint. The impromptu clearances were terminated when the final approach course was reached. The flight then proceeded to execute a low approach to Runway 4 rather than a full stop landing as in the previous STAR.

The low approach was maintained to the departure end of Runway 4 at which time the flight proceeded direct to BRAVO waypoint. The SID continued direct to ROMEO waypoint. After reaching ROMEO waypoint the SID terminated and the return enroute segment from ROMEO to CAPE MAY was flown. (See Figure 4.12 for route orientation).

Shortly after initiation of the Loran-C experimental flights it was decided to modify the test plan to include three types of area navigation non-precision approaches. The three types were expected to provide information regarding Loran-C navigation accuracy capabilities using uncalibrated, charted lat/long input data, pre-flight calibrated lat/long input data and measured time difference input data for the final approach waypoints. These data were collected and the results are presented in Section 5.13.

Table 4.2 presents the detailed waypoint location information (latitude/longitude), course information (true/magnetic) and the appropriate along track distances for each of the NAS route segments.

Table 4.2 NAS Pattern Waypoint Definition

WAYPOINT	LATITUDE (N)	LONGITUDE (W)	TRUE COURSE (deg)	MAGNETIC COURSE (deg)	ALONGTRACK DISTANCE (nm)
Cape May (CM)	038° 56.63'	074° 53.08'	—	—	—
Victor (V)	039° 14.00'	074° 15.00'	315.5	325.5	24.3
Golf (G)	039° 22.00'	074° 57.50'	059.4	069.4	15.7
Hotel (H)	039° 17.23'	074° 41.83'	111.3	121.3	13.0
India (I)	039° 22.53'	074° 38.18'	028.0	038.0	6.0
MAP (R/W 04)	039° 26.95'	074° 35.15'	028.0	038.0	5.0
Bravo (B)	039° 30.05'	074° 33.01'	028.0	038.0	3.5
Romeo (R)	039° 32.50'	074° 40.00'	294.4	304.4	5.9
Sierra (S)	039° 12.50'	074° 53.00'	206.8	216.8	22.4
S-V	—	—	275.1	285.1	17.1
R-CM	—	—	195.8	205.8	37.2

BEST AVAILABLE COPY

ATLANTIC CITY, N.J. SID
NAFEC ATLANTIC CITY

ATLANTIC CITY ONE RNAV DEPARTURE

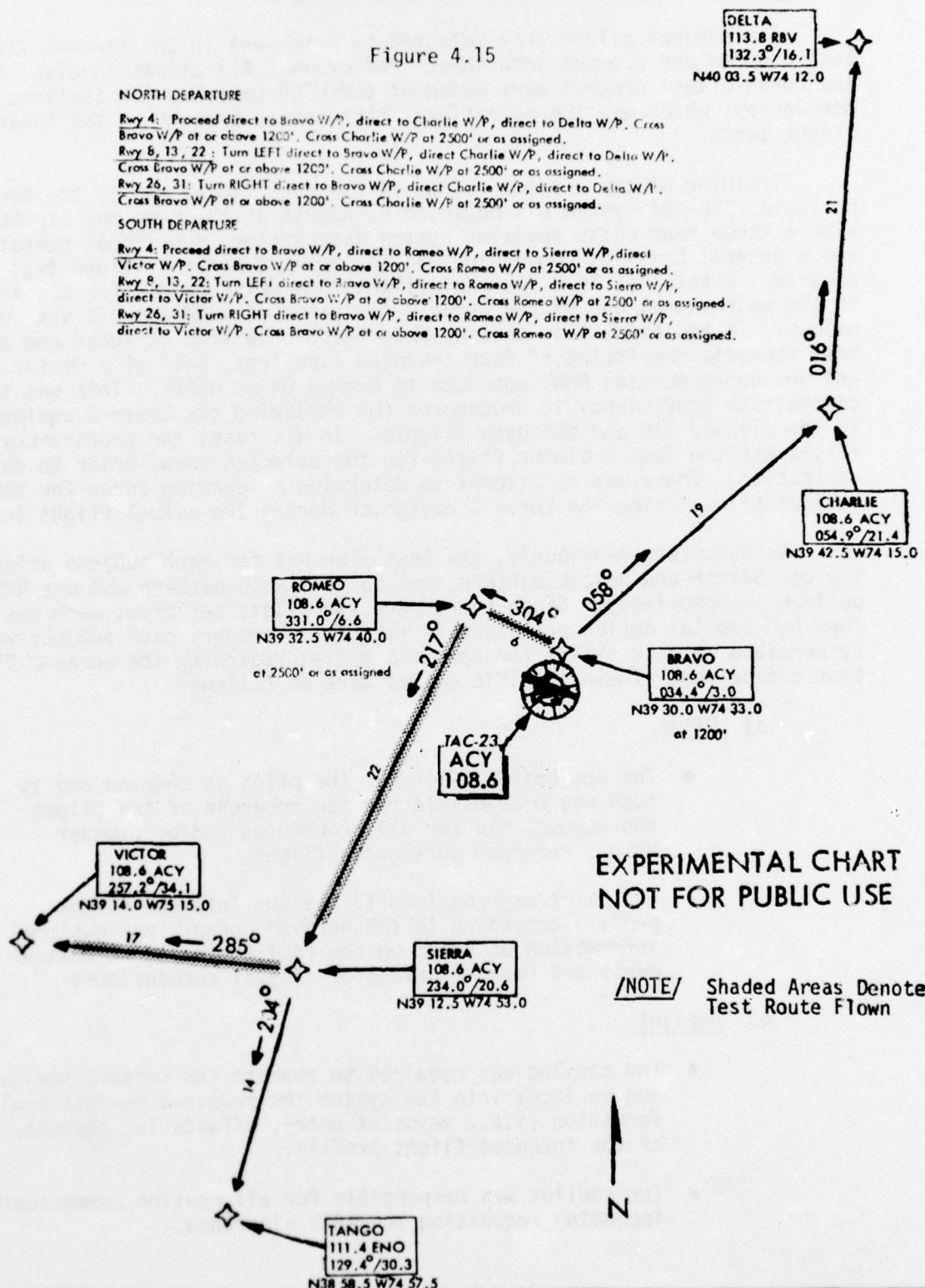
Figure 4.15

NORTH DEPARTURE

Rwy 4: Proceed direct to Bravo W/P, direct to Charlie W/P, direct to Delta W/P. Cross Bravo W/P at or above 1200'. Cross Charlie W/P at 2500' or as assigned.
Rwy 8, 13, 22: Turn LEFT direct to Bravo W/P, direct to Charlie W/P, direct to Delta W/P. Cross Bravo W/P at or above 1200'. Cross Charlie W/P at 2500' or as assigned.
Rwy 26, 31: Turn RIGHT direct to Bravo W/P, direct to Charlie W/P, direct to Delta W/P. Cross Bravo W/P at or above 1200'. Cross Charlie W/P at 2500' or as assigned.

SOUTH DEPARTURE

Rwy 4: Proceed direct to Bravo W/P, direct to Romeo W/P, direct to Sierra W/P, direct to Victor W/P. Cross Bravo W/P at or above 1200'. Cross Romeo W/P at 2500' or as assigned.
Rwy 8, 13, 22: Turn LEFT direct to Bravo W/P, direct to Romeo W/P, direct to Sierra W/P, direct to Victor W/P. Cross Bravo W/P at or above 1200'. Cross Romeo W/P at 2500' or as assigned.
Rwy 26, 31: Turn RIGHT direct to Bravo W/P, direct to Romeo W/P, direct to Sierra W/P, direct to Victor W/P. Cross Bravo W/P at or above 1200'. Cross Romeo W/P at 2500' or as assigned.



4.3 SUBJECT PILOTS

Six subject pilots were selected to take part in the Loran-C flight test program and grouped into three test crews. All pilots involved in the Loran-C test program were based at the USCG Cape May Air Station, New Jersey, which was the operational test center throughout the Loran-C flight tests.

Training of the subject pilots in the operational use of the Loran-C navigator TDL-424 system was begun on 31 August at the Cape May Air Station with a three hour class covering system description, functional operation and a general briefing concerning the forthcoming Loran-C flight test program. A total of 14.0 hours of flight time was provided for training in the operational use of the Loran-C navigator divided amongst six subject pilots. In addition, when testing began each crew flew at least one special test scenario consisting of four creeping line legs, half of a sector search and one non-precision RNAV approach to Runway 04 at NAFEC. This was to demonstrate proficiency in procedures for utilizing the Loran-C equipment in the planned SAR and NAS data flights. In all cases the proficiency flight was the last training flight for the selected crews prior to data collection. There was no attempt to determine a learning curve for the subject pilots using the Loran-C navigator during the actual flight testing.

As discussed previously, the test plan was for each subject pilot to fly one Search and Rescue pattern, one Surveillance pattern and one NAS pattern, respectively. Since there were two pilots per crew, each one of them had copilot duties on alternate flights. However, each subject was responsible on each flight for specific duties regarding the Loran-C flight test evaluation. These specific duties were as follows:

a) Pilot

- The designated pilot was the pilot in command and as such was responsible for the progress of the flight and accountable for all procedures and/or blunder errors recorded during his flight.
- The pilot was required to fly the intended flight profile according to the derived Loran-C navigational information as shown on the applicable flight instruments and Loran-C navigator display combinations.

b) Copilot

- The copilot was required to operate the Loran-C navigator and to input into the system the required navigational information (i.e., waypoint entry, offsets leg changes, etc.) of the intended flight profile.
- The copilot was responsible for all routine communications, including requesting the RNAV clearance.

- The copilot was expected to assist the pilot in the monitoring of flight instruments, safety of flight, and to provide "callouts" (i.e., new leg being used, arriving at a waypoint, begin turn, descend to a required altitude, desired track heading, etc.) as required, to assure the success of the mission as would normally be required under actual USCG operating conditions.

A summary of each subject pilot's experience level is presented in Table 4.3.

Table 4.3 Flight Experience of Subject Pilots in Hours

SUBJECT PILOT	TOTAL	ROTARY WING	FIXED WING
A	2068	1819	249
B	483	371	112
C	553	432	121
D	942	820	122
E	833	715	118
F	429	303	126

The subject pilots were grouped into three different crews, as follows:

First Crew: Subject Pilots A and B
 Second Crew: Subject Pilots C and D
 Third Crew: Subject Pilots E and F

4.4 DATA ACQUISITION

This section discusses the methods of data acquisition in the Loran-C flight test program. There were three categories or classes of data that were recorded during the Loran-C flight test program for the purposes of the various levels of analysis required to support the Loran-C operational evaluation. The three distinct types of recorded data were:

- a) Airborne Instrumentation Data
- b) Ground Reference Data
- c) Manually Recorded Flight Logs

The following paragraphs discuss each of these different methods of data acquisition.

4.4.1 Airborne Instrumentation

The airborne instrumentation consisted of electronically recording selected parameters from the Loran-C receiver on a Teledyne Loran Route Verification (LRV) digital cassette recorder system. The following parameters were recorded on the LRV data recorder: Loran-C indicated aircraft position (latitude and longitude), Distance-to-Waypoint (DTW), Cross Track Deviation (CTD) and Real Time. The LRV recorder is a portable unit which operates on its own batteries. Due to the design characteristics of the recorder, the rate at which the parameters were recorded was approximately 7 samples per minute or one sample per 0.2 nautical miles, the latter being based on the relatively slow cruise airspeed (80Kts) of the HH-52A test helicopter.

4.4.2 Ground Reference Data

The ground reference data was obtained using the NAFEC "Extended Area Instrumentation Radar" (EAIR). The EAIR radar was utilized as the indicator of actual aircraft position, by detecting and recording (real time) the azimuth, elevation and altitude of the test aircraft. EAIR is a precision, C-band tracking radar which provides the slant range, azimuth angle and elevation angle of an aircraft (radar cross section of 1 square meter) within a range of 100 nautical miles when operating in the skin tracking mode, with a maximum distance of 190 nautical miles when operated in the beacon tracking mode. (All of the Loran-C test flights were tracked in beacon tracking mode). The slant range obtained by the EAIR facility is accurate within 20 yards and the azimuth angle and elevation angle are accurate within 0.011 degrees. For example, at 50 miles the accuracy would be 20 yards in range and 20 yards in azimuth and elevation. The radar antenna can track a target 360° in azimuth and from 0° to +89° in elevation. The antenna can be directed as low as minus one and one-half degrees in elevation.

4.4.3 Manually Recorded Flight Logs

During all flight tests a trained cockpit observer monitored and kept an accurate log of routine and special events that occurred during the flight. The observer was responsible for documenting the crew workload and performance, the issuing of impromptu traffic clearance (NAS tests) and monitoring the LRV data recording system. The flight logs recorded by the observer were a major source of data acquisition from which flight test results could be operationally evaluated. Following is a summary of flight test data recorded by the cockpit observer, pertinent to the relative evaluation of test objectives.

- 1) Procedural Errors
- 2) Input Errors
- 3) Loran-C Display Mode
- 4) Waypoint in Use
- 5) Waypoint Sequencing Mode (auto/manual)

- 6) Major Cross Track Deviations (CDI)
- 7) Overshoots/Undershoots
- 8) Execution of Offsets/Impromptu Maneuvers
- 9) Heading Intercepts
- 10) Pilot Workload (communications, traffic, etc.)

4.4.4 Analysis Requirements

The three categories or classes of data recorded were used for the various levels of analysis necessary to support the Loran-C operational evaluation. This section discusses the data obtained for all phases of the Loran-C flight test program.

Table 4.4 summarizes the data acquisition requirements which were used to support the AC 90-45A demonstration of compliance evaluation. The parameters recorded were classified according to the previously developed basic data recording categories.

Table 4.4 Data Requirements

1) <u>Digitally Recorded Navigation Data</u>	
Ground Based	- Actual Aircraft Position from Tracking Radar
	- Time
Airborne	- Loran-C Indicated Aircraft Position
	- Cross Track Deviation (HSI Needle Deflection)
	- Along Track Distance (nm) To/From the Waypoint in Use
	- From/To Indicator
	- Time (Correlated with Tracking Radar)
	- Waypoint in Use (Optional)
	- Desired Track (Optional)
	- Track Angle Error (Optional)
2) <u>Manually Recorded Data Logs</u>	
Procedural Errors	
Input Errors	
Loran-C Display Mode	
Waypoint in Use	
Waypoint Sequencing Mode (Auto/Manual)	
Desired Track	
Heading	
Loran-C Operation Mode (Auto/Manual, Lat/Lon or Time/Difference, etc.)	
Pilot Workload (communications, weather, traffic, etc.)	

Data requirements for the operational testing were not as stringent as those demanded for verification of AC 90-45A compliance accuracy. For the SAR missions, there were no requirements for statistical accuracy data. Rather, the ability of pilots to utilize the Loran-C navigator to effectively maintain proper track spacing and sweep width was the primary concern. Therefore, data requirements for this portion of the Loran-C operational evaluation were simply an accurate knowledge of actual aircraft path vs desired SAR profile. This requirement was satisfied using the ground based radar tracking data only. The radar C-band beacon antenna was calibrated at least every other day to insure the tracking accuracy stated in Section 4.4.2. The calibration procedure was to land at NAFEC and taxi to a known position (designated P.115). Radar lock-on was achieved and position accuracy verified. Additional manually recorded data and airborne data were used to augment the analysis and provide explanatory information when track deviations occurred, but this type of data was not an explicit requirement.

Data requirements for establishing the absolute accuracy and statistical position error information necessary to document Loran-C applicability to surveillance and enforcement operations were also less stringent than the AC 90-45A compliance requirements. In this case, the airborne Loran-C indicated position was of primary importance. Helicopter hovers near fixed and movable selected reference points were used to collect Loran-C repeatability and absolute position accuracy data. The indicated Loran-C position data was compared to known desired location data and converted to errors in latitude (L) and longitude (λ) in feet. The L , λ errors were then mathematically combined from successive readings to determine mean position errors and circular error probability statistics.

As previously discussed, the data acquisition and processing requirements for the oil rig industry were identical to those already described for surveillance.

4.5 DATA REDUCTION

This section describes the techniques used to develop analytically meaningful data from the data recorded both automatically and manually. Section 4.5.1 presents a summary of the experimental procedure used which was designed to provide adequate data samples over each route tested. Section 4.5.2 discusses the calculation procedure used to combine these data samples in the manner specified for AC 90-45A compliance and in the manner required for calculating position error data for surveillance accuracy. Finally, Section 4.5.3 presents the details of how the acquired digital data were processed and aggregated across flights.

4.5.1 Experimental Procedure

The following section describes and summarizes with tables the various test scenarios flown (NAS, SAR and Surveillance) from a data sampling and pilot scheduling viewpoint.

Table 4.5 SAR Flight Test Matrix Flown

Enroute Segment	Search Pattern	Alongtrack Distance (nm)	Times Flown Per Pilot						Total Times Flown (Sample Size)	Total Distance (nm)
			A	B	C	D	E	F		
Cape May-CSP (Creeping Line)	Creeping Line	8	1	1	1	1	1	1	5	40
		40	1	1	1	1	1	1	5	200
		34	1	1	1	1	1		4	136
End Sector Search-CSP (Expanding Square)	Expanding Square	9	1	1	1	1	1	1	5	45
		24	1	1	1	1	1	1	5	120
		22	1	1	1	1	1	1	5	110

A. SAR Operation Flight Test Matrix

A total of five flights were flown utilizing the Loran-C navigator during the SAR operational tests. As previously discussed, a SAR mission on a given flight consisted of flying a total of three SAR patterns: Sector Search, Creeping Line and an Expanding Square pattern, respectively. All the SAR patterns were flown after updating the Loran-C navigator at the Cape May helipad location prior to each flight. Table 4.5 shows the number of times each SAR pattern was flown per pilot, as well as the total number of patterns flown during the tests. Two additional SAR flights were flown without utilizing the Loran-C navigator but using conventional VOR/DME navigation techniques. The purpose of these two flights was to obtain baseline data for comparison to the other SAR flights which utilized the Loran-C navigator. As can be seen from Table 4.5 a total of 14 SAR patterns were flown, as follows: 5 Creeping Line; 4 Sector Search and 5 Expanding Square patterns, respectively. In addition an enroute segment (22 nm) was flown 5 times from the end of the Expanding Square pattern to the Cape May Air Station, simulating the return segment from the end of a SAR mission to a landmark. It is considered that, although the number of SAR patterns flown by each pilot was relatively small, a thorough evaluation of the Loran-C navigator, as well as a demonstration of its potential utilization in the execution of SAR patterns, was accomplished.

B. Surveillance Flight Test Matrix

Due to schedule conflicts only one operational surveillance test flight was possible during the Loran-C flight test program. As previously discussed in Section 4.3.2 the surveillance tests consisted of determining the accuracy and repeatability of the Loran-C Navigator by hovering the test helicopter over a previously defined location. Table 4.6 presents a distribution of the surveillance flight test matrix. Although the surveillance tests were limited to one flight, the test data obtained was quite sufficient due to: (1) the minimum scatter of the data recorded, (2) the consistency in the number of data samples per target, and (3) the satisfactory degree of demonstrated repeatability.

Table 4.6 Surveillance Flight Test Matrix Flown

Target	Number of Hover	Number of Data Samples	Distance IP Offshore (nm)
Five Fathom Bank Buoy	2	19	16
Buoy No. 8	2	18	3
Sea Isle Vortac	2	20	(Inland)
Deadman's Shoal Buoy	2	19	3
Brandywine Lighthouse	2	20	7
Total	10	96	—

C. NAS Flight Test Matrix Flown

A total of six (6) flights were flown during the NAS testing. Table 4.7 summarizes the NAS flight test enroute, SID, STAR and final approach data acquired. As shown in this table each subject pilot flew two complete circuits of the entire NAS profile (Figure 4.12). As described previously in Section 4.3.3, the NAS test scenario for each pilot consisted of two enroute segments, two SIDs, two STARs and two approaches, one to a full stop and one low approach. This number of segments per subject pilot resulted in a total of twelve enroute segments over approximately 372 nautical miles, twelve SIDs and twelve STARs or a total of twenty-four terminal area segments, and twelve final approaches. This number of flights per flight regime has been shown to provide adequate, normally distributed total system error, flight technical error, and airborne equipment error statistics in previous RNAV flight tests conducted by the FAA and reported in Reference 2.

Shortly after the test program began it was decided to obtain non-precision approach data using two additional TDL-424 waypoint input modes. These were:

- a) Charted lat/long waypoint location data input and updating the Loran-C navigator using the known position at the gate (helipad) on Cape May Air Station.
- b) Measured waypoint location data input in time differences.

The non-precision approach data taken using these two modes offers the user a more accurate navigation capability over the basic mode tested, that is, non-updated waypoint input data taken directly from the charts.

In addition to the error budget statistics suitable for demonstration of compliance accuracy, the impromptu maneuvers performed during this NAS testing are indicative of operationally meaningful RNAV maneuvers such as extending the downwind leg, base leg offsets and impromptu direct to RNAV clearances.

4.5.2 Performance Assessment

A. NAS Analysis

The acceptable means of compliance for demonstrating Loran-C capabilities as an area navigation system suitable for NAS operations are currently delineated in FAA Advisory Circular 90-45A, Appendix A, Section 2[4]. This advisory circular section is further subdivided into accuracy requirements (2.a), system design requirements (2.b), equipment installation specifications (2.c), and flight manual information requirements (2.d). The data collected during the Loran-C flight testing is primarily applicable to the accuracy requirements for compliance. Therefore, in order to understand the need for specific data reduction techniques, the accuracy requirements for 2D navigation systems of Appendix A Section 2.a of AC 90-45A are reproduced in their entirety.

Table 4.7 NAS FLIGHT TEST MATRIX*

ENROUTE AFEC ONE RNAV ARRIVAL (STAR)

RNAV Route		Alongtrack Distance (nm)	Times Flown Per Pilot						Total Times Flown (sample Size)	Total Distance (nm)
Type	Segment		A	B	C	D	E	F		
Enroute	CAPE MAY-VICTOR	24	1	1	1	1	1	1	6	144
STAR	VICTOR-GOLF	16	2	2	2	2	2	2	12	192
STAR	GOLF-HOTEL (as filed)	13	1	1	1	1	1	1	6	78
STAR/Impromptu	GOLF-HOTEL (3.0 nm right offset to intercept final approach course)	13	1	1	1	1	1	1	3	39
STAR/Impromptu	GOLF-HOTEL-INDIA (3.0 nm left offset/direct-to INDIA)	13	1	1	1	1	1	1	3	39
2D RNAV Approach	HOTEL-INDIA	6	1	2	1	2	1	2	9	54
2D RNAV Approach	INDIA-MAP (R/W 04)	5	2	2	2	2	2	2	12	60
ATLANTIC CITY ONE RNAV DEPARTURE (SID)/ENROUTE										
SID	MAP-BRAVO (from previous low approach)	3	2	2	2	2	2	2	12	36
SID	BRAVO-ROMEO	6	2	2	2	2	2	2	12	72
SID	ROMEO-SIERRA	22	1	1	1	1	1	1	6	132
SID	SIERRA-VICTOR	17	1	1	1	1	1	1	6	102
ENROUTE	ROMEO-CAPE MAY	37	1	1	1	1	1	1	6	228

*A total of 6 non-precision approaches were flown at the conclusion of the NAS flight test utilizing the Loran-C update mode capabilities and charted waypoint coordinates from HOTEL Waypoint to the MAP Waypoint (R/W 04).

2/21/75

A. ACCEPTABLE MEANS OF COMPLIANCE (FOR USE UNDER INSTRUMENT FLIGHT RULES)

An acceptable means of compliance with Section -.1301, -.1309, -.1431, and -.1581, of Part 23, 25, 27 or 29 (as applicable), with respect to area navigation systems, provided for use under IFR conditions, is to satisfy the criteria set forth in this paragraph.

a. Accuracy.

- (1) 2-D RNAV System using Reference Facility for continuous navigation information. The total of the error contributions of the airborne equipment (receivers plus area navigation - including desired track setting as well as waypoint setting errors) when combined RSS with the following specific error contributions should not exceed the error values shown in Table 1, Appendix A.

VOR ground station	$\pm 1.9^\circ$
DME ground station	± 0.1 NM

- (2) 2-D RNAV systems which use VOR/DME information from other than the Reference Facilities must show that the algorithm used will always select a station that will provide cross track/along track errors equal to or less than the greater of the RNAV system errors of the reference facility for any RNAV track (Table 1) or the errors shown in paragraph 2.a. (3).
- (3) 2-D RNAV System not using VOR/DME for continuous navigation information. The total of the error contributions of the airborne equipment (including update, aircraft position and computational errors), when combined with appropriate flight technical errors listed in 2.a. (4) below, should not exceed the following with 95% confidence (2-sigma) over a period of time equal to the update cycle:

	<u>Cross Track</u>	<u>Along Track*</u>
Enroute	2.5 NM	1.5 NM
Terminal	1.5 NM	1.1 NM
Approach	0.6 NM	0.3 NM

- (4) 2-D Flight Technical Errors (FTE) when combined RSS with the errors discussed in (1) and/or (a) above determine the Total System error. The Total System error is used by airspace planners and includes the following specific FTE values for determining cross-track position accuracies.

*NOTE: Although there is no track keeping accuracy requirement in the along track direction for 2D RNAV systems or any pilot display of along track deviation for 2D systems, these error budget values for enroute, terminal and approach are airborne system error requirements without considering the FTE values from paragraph 2.a. (4).

Values larger than these must be offset by corresponding reduction in other system errors. (See Appendix C) No FTE is used in determining the along-track accuracy.

Enroute	±2.0 NM
Terminal	±1.0 NM
Approach	±0.5 NM

Several data acquisition requirements evolve upon thorough examination of these AC 90-45A accuracy requirements. First, total system error must be quantified. Second, the error contributions of the "airborne equipment" must be measured. (Airborne equipment error includes errors in Loran-C position due to transmission and propagation induced signal errors). Finally, the value of Flight Technical Error (FTE) must be measured. Upon satisfactorily instrumenting an aircraft and recording these parameters, the procedures of AC 90-45A Appendix C can be used to combine the error elements into an acceptable error budget. These procedures are based on the assumptions that the variable errors from each of the error sources are normally distributed and independent. In this case, the errors may be combined in RSS (root-sum-square) fashion in order to demonstrate compliance. That is, the standard deviations, σ_{FTE} and $\sigma_{\text{Airborne Equipment}}$

may be combined by taking the square root of the sum of the squares:

$$\sigma_{\text{Total System}} = \sqrt{\sigma_{FTE}^2 + \sigma_{\text{Airborne Equipment}}^2} \quad (a)$$

Using this recommended equation and rearranging terms, the implied budget for airborne equipment may be calculated from the values for total system error and FTE listed in Appendix A of AC 90-45A. That is,

$$\sigma_{\text{Airborne Equipment}} = \sqrt{\sigma_{\text{Total System}}^2 - \sigma_{FTE}^2} \quad (b)$$

The resulting values for the demonstration of compliance of the Loran-C navigator system have been calculated. These are:

	<u>Airborne Equipment</u>
Enroute	1.5 nm
Terminal	1.12 nm
Approach	0.33 nm

As previously noted, the airborne equipment error budget inherently includes errors in Loran-C position due to transmission and propagation errors. In addition, the airborne equipment error budget includes all signal filtering, processing, computational, output and display errors associated with the airborne Loran-C navigator system. Also, as pointed out in the footnote on the along track error budget of AC 90-45A, Appendix A, paragraph

2.a. (4), the airborne equipment error budget values correspond to the cross track error budget values of paragraph 2.a. (3) with the FTE subtracted as shown in equation (b).

This methodology was used to compare and evaluate the Loran-C navigator system from an AC 90-45A and NAS compatibility viewpoint. The results of this comparison are summarized in Section 5.1.

B. SAR Analysis

This data analysis section summarizes the techniques used for presenting and analyzing the data collected for the three search patterns normally used in Coast Guard operations. The data processing for these three patterns was limited to the actual aircraft track information provided by the precision tracking radar. The primary goal of this portion of the evaluation was to determine the adequacy and repeatability of the Loran-C navigator in the execution of creeping line, expanding square and sector search profiles. The most straightforward and meaningful technique to achieve this goal was simply to present successive test flight tracks overlayed on the desired patterns. The analysis was centered around the adequacy or inadequacy of the Loran-C performance. Commentary and interpretation of deviations from the desired track due to equipment functional limitations, procedural errors or pilot workload are provided using the flight test observer's logs. These data are discussed in detail in Sections 5.2 and 5.4.

In addition to the qualitative analysis of Loran-C accuracy and repeatability, it was decided to compute the improvement in probability of detection (POD) as an exercise for the creeping line search pattern only. The probability of detection (POD) relationships which are contained in the National Search and Rescue Manual (CG-308) are based on the assumption that the desired track will be adhered to throughout the search pattern. The ability of the search aircraft to fly an accurate search pattern is dependent upon the accuracy of the navigation system.

The method used to compute POD requires understanding of several basic definitions:

let P = probability of detection (POD) of a target within a given search area

$$\text{then } P = \int_0^L p d\ell \approx \sum_{i=1}^n p_i \quad (1)$$

where ℓ = distance along search legs

L = total search leg length = pattern width x no. of search legs
for a creeping line search

p = POD (ℓ)

p_i = POD at point i

$$P_i = P_i(A|B) \cdot p_i(B) = P_i(A \cdot B) = P(A) \cdot P(B)$$

where

$p(A) \equiv$ probability of detecting target assuming the target is within the search area

and

$p(B) \equiv$ probability that the target is located within the search area (i.e. within \bar{S} of the search aircraft)

where \bar{S} is defined as a distance of magnitude S along a path parallel to the creeping line search axis to the right or left

then, $p_i(A|B) = f(\frac{W}{S_i})$ as defined in CG-308, (Figure 8-65) (2)

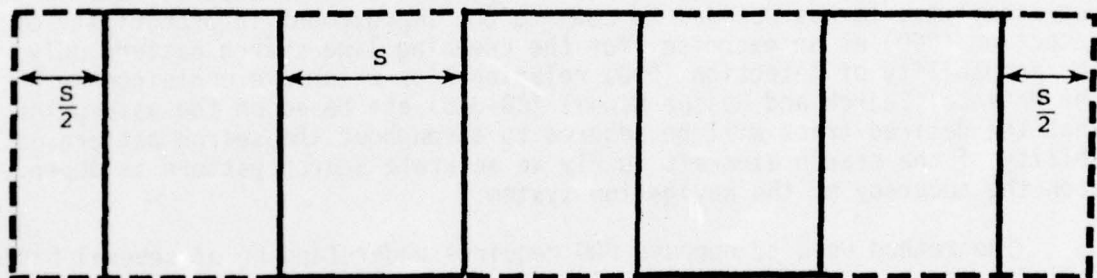
and, for a datum area:

$$p_i(B) = \frac{S_i}{nS} \quad (3)$$

where s = desired track spacing

assume that a datum area of interest is defined as shown in Figure C .

Figure C

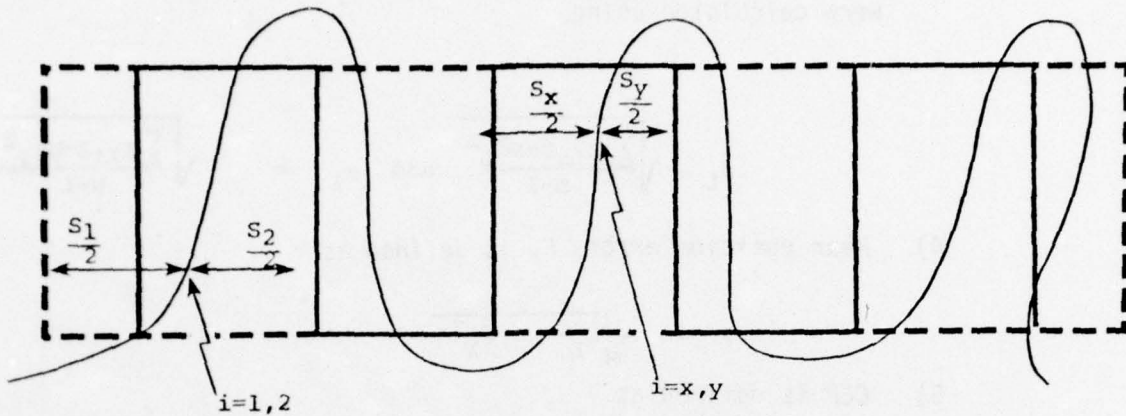


combining Equations (1), (2) and (3):

$$P = \frac{1}{nS} \sum_{i=1}^n S_i f(\frac{W}{S_i}) \quad (4)$$

Equation (4) is applied within the datum area, such that $\frac{S_i}{2}$ is defined as the distance along the CS axis from point i half way to the adjacent track, or the distance to the edge of the datum area, as illustrated in Figure D.

Figure D



The POD results obtained using these relationships is discussed in Section 5.2.1.

C. SURVEILLANCE/OIL RIG ACCURACY AND REPEATABILITY DATA

The data analysis necessary to determine and document the accuracy and repeatability of the Loran-C navigator for surveillance and off-shore oil industry applications is presented in this section. The calculation procedure and data aggregation technique for this analysis was taken from Reference 5. Data taken during hovering flight over precisely defined locations was combined into mean error, (F), and Circular Error Probability (CEP), statistics as follows:

- 1) Recorded Loran-C indicated position, latitude and longitude, for a minimum of two minutes (approximately twenty position readings) were converted to error data in latitude and longitude.
- 2) These error statistics (in feet) were reduced to mean position errors using

$$\bar{\epsilon}_L = \sum_{i=1}^N \frac{\epsilon_{Li}}{N} \quad \text{and} \quad \bar{\epsilon}_\lambda = \sum_{i=1}^N \frac{\epsilon_{\lambda i}}{N}$$

- 3) The standard deviation of the latitude and longitude errors were calculated using

$$\sigma_L = \sqrt{\frac{\sum \epsilon_{Li}^2 - N\bar{\epsilon}_L^2}{N-1}} \quad \text{and} \quad \sigma_\lambda = \sqrt{\frac{\sum \epsilon_{\lambda i}^2 - N\bar{\epsilon}_\lambda^2}{N-1}}$$

- 4) Mean position error, F, is defined as

$$F = \sqrt{\bar{\epsilon}_L^2 + \bar{\epsilon}_\lambda^2}$$

- 5) CEP is defined as

$$\text{CEP} = 0.59 (\sigma_L + \sigma_\lambda) \pm 3\%$$

$$\text{if} \quad \frac{\sigma_\lambda}{3} < \sigma_L < 3\sigma_\lambda$$

These accuracy statistics are summarized in Section 5.3.

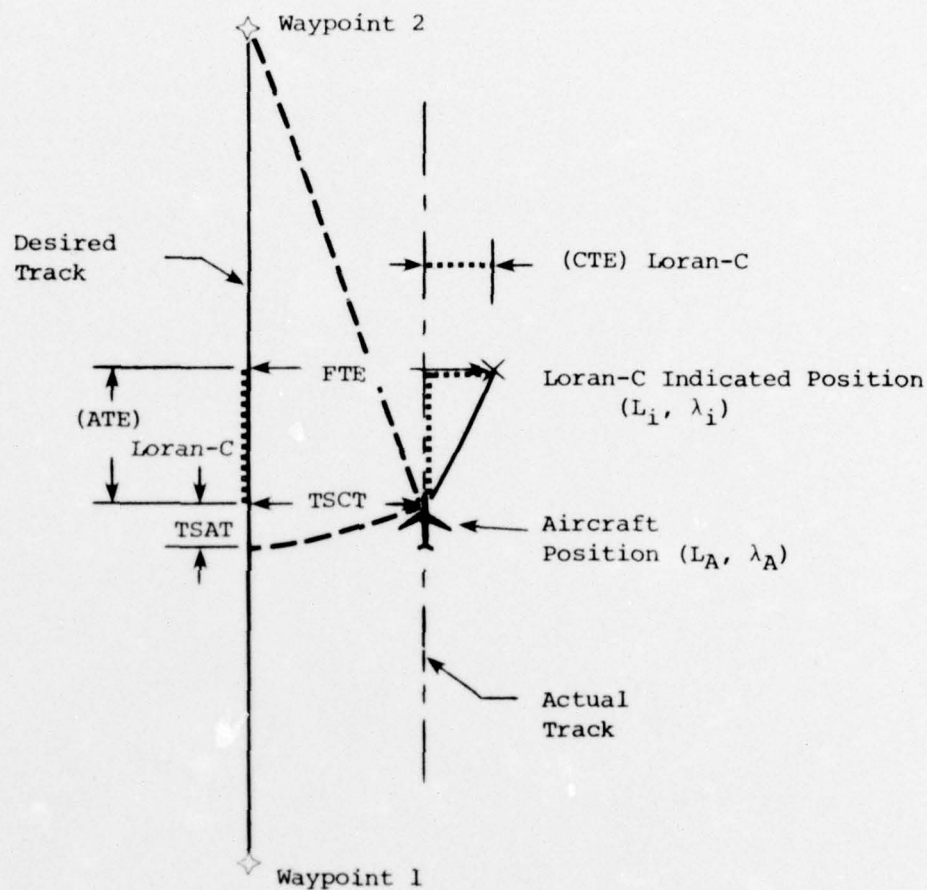
4.5.3 Statistical Treatment

This section outlines the step-wise procedure used for data reduction of the NAS flight test data. The major functional elements of the data reduction system are as follows:

- Airborne Data Editing
- Radar Data Editing
- Airborne Radar Data Merge (time correlated)
- Computation of TSCT, ATE, CTE, and FTE
- Compute mean and standard deviation (2σ) of above variables for each route segment of each flight.
- Statistical Aggregation over each route segment and total

The airborne and radar merge data were edited (data extracted) of samples judged to be invalid; i.e., due to blunders, dropouts, known EAIR radar calibration problems, etc. The merge program organized the data by flight segments which terminate at the bisector of the track angle change. Data

reduction concluded with the statistical analysis and data aggregation program. These programs produced TSCT, ATE, CTE, and FTE statistics defined as shown in the following schematic:



where

- TSCT = Total System Cross Track Error
- ATE = Airborne Equipment Along Track Error
- CTE = Airborne Equipment Cross Track Error
- FTE = Flight Technical Error

These statistics were generated by flight for each route segment, across all flights on a given route segment by subject pilot experience level, and total aggregate statistics for all flights, all segments and all pilots per SID/STAR, enroute and final approaches.

5.0

DISCUSSION OF RESULTS AND ANALYSIS

The purpose of this section is to provide detailed insight into the flight test results and data analysis for the Coast Guard operational flight testing of the Loran-C navigator. The details presented in this section represent the results of a comprehensive review of the specific data collected during the evaluation of the Loran-C navigator.

This section is divided into five subsections of data analysis for ease of reference. These categories are:

- 5.1 NAS/AC 90-45A Accuracy Analysis
- 5.2 SAR Operational Analysis
- 5.3 Surveillance/Oil Rig Analysis
- 5.4 Blunder/Workload Analysis
- 5.5 Operational Evaluation of the Prototype Loran-C Navigator

5.1 NAS/AC 90-45A ACCURACY ANALYSIS

This section describes the data collected and analyzed pertinent to the twofold purpose of the NAS testing. These purposes were: first, to demonstrate the applicability and compatibility of the Loran-C navigator as an area navigation system operating in the current NAS environment and second, to determine and document the accuracy of the Loran-C navigator in a manner suitable for demonstration of compliance with the requirements of AC 90-45A. The former objective deals primarily with the track keeping accuracy and airspace utilization observed using Loran-C as the primary navigation system for enroute, terminal and approach airspace. The latter objective requires detailed statistical data aggregation, processing and analysis as discussed in detail in Section 4.5.

Section 4.5.2 delineated the current enroute, terminal and approach accuracy limits for the Loran-C navigator system. These are:

<u>AIRSPACE</u>	<u>TSCT</u>
Enroute	2.5 nm
Terminal	1.5 nm
Approach	0.6 nm

These accuracy limits will be superimposed on all subsequent aircraft tracks obtained during the NAS testing of the Loran-C navigator. It should be noted that these limits are significantly more stringent for enroute and terminal airspace than currently imposed by FAA Handbook 7110.18, "Air Traffic Control Service for Area Navigation Equipped Aircraft Operating in the United States National Airspace System". In addition, these requirements are also more stringent than similar requirements placed on VOR/DME referenced area navigation equipment except for regions in close proximity to the VORTAC station.

Nevertheless, the following analysis will show that the Loran-C navigator system satisfactorily performed within these tighter airspace limits for all regions of interest. This satisfactory performance was obtained without any special update procedures or system initialization prior to the NAS routes. The area navigation waypoint information was pre-specified on the charts shown in Section 4.2, stored in the Loran-C navigator and flown in a manner compatible with the expected characteristics of an actual NAS user application.

5.1.1 Enroute Results

Figure 5.1 illustrates the results of the enroute flight testing. Two enroute segments were flown as an integral part of the experimental design. The CAPE MAY to VICTOR route segment was twenty-four nautical miles long and was used to intercept the NAFEC ONE RNAV ARRIVAL (STAR) at VICTOR waypoint. The ROMEO to CAPE MAY enroute segment was thirty-seven nautical miles long and was used to return to CAPE MAY upon departure via the ATLANTIC CITY ONE RNAV DEPARTURE (SID). As can be seen in the figure, all Loran-C flights stayed well within the ± 2.5 nm AC 90-45A limits for Total System Cross Track (TSCT) error. In fact, five of the six flights, CAPE MAY to VICTOR and four of the five flights, ROMEO to CAPE MAY, stayed within ± 1.0 mile of the desired track. These flights in general indicated very accurate and repeatable track keeping ability with only a slight bias (about 0.5 nm) to the right or left of track depending on track heading and direction of flight.

The two flights on Figure 5.1 which deviated significantly from the desired track were explained as follows:

1. On the CAPE MAY to VICTOR route segment, one pilot selected present position direct to VICTOR rather than the desired and properly programmed route segment connecting the proper waypoints.
2. On the ROMEO to CAPE MAY route segment, one aircraft track was essentially invalid due to a tracking radar calibration problem. The gap in this track near CAPE MAY indicates an attempt at recalibration which also failed.

In summary, it can be seen that the Loran-C navigator system performed well within the AC 90-45A specified enroute accuracy limits of ± 2.5 nm for a total of nine experimental flights over enroute segments typical of area navigation operations. Section 5.1.4 discusses this performance quantitatively and shows that the two-sigma measured total system cross track error for these enroute flights was less than ± 0.6 nm.

5.1.2 Terminal Area Results

Figures 5.2 and 5.3 present the composite terminal area maneuvering TSCT data obtained during SID and STAR testing respectively. It should be noted that the AC 90-45A limits on these figures are ± 1.5 nm. The summary of flights on each route segment are as shown in Table 5.1.

Figure 5.1 Aircraft Flight Profiles During the Enroute Segments

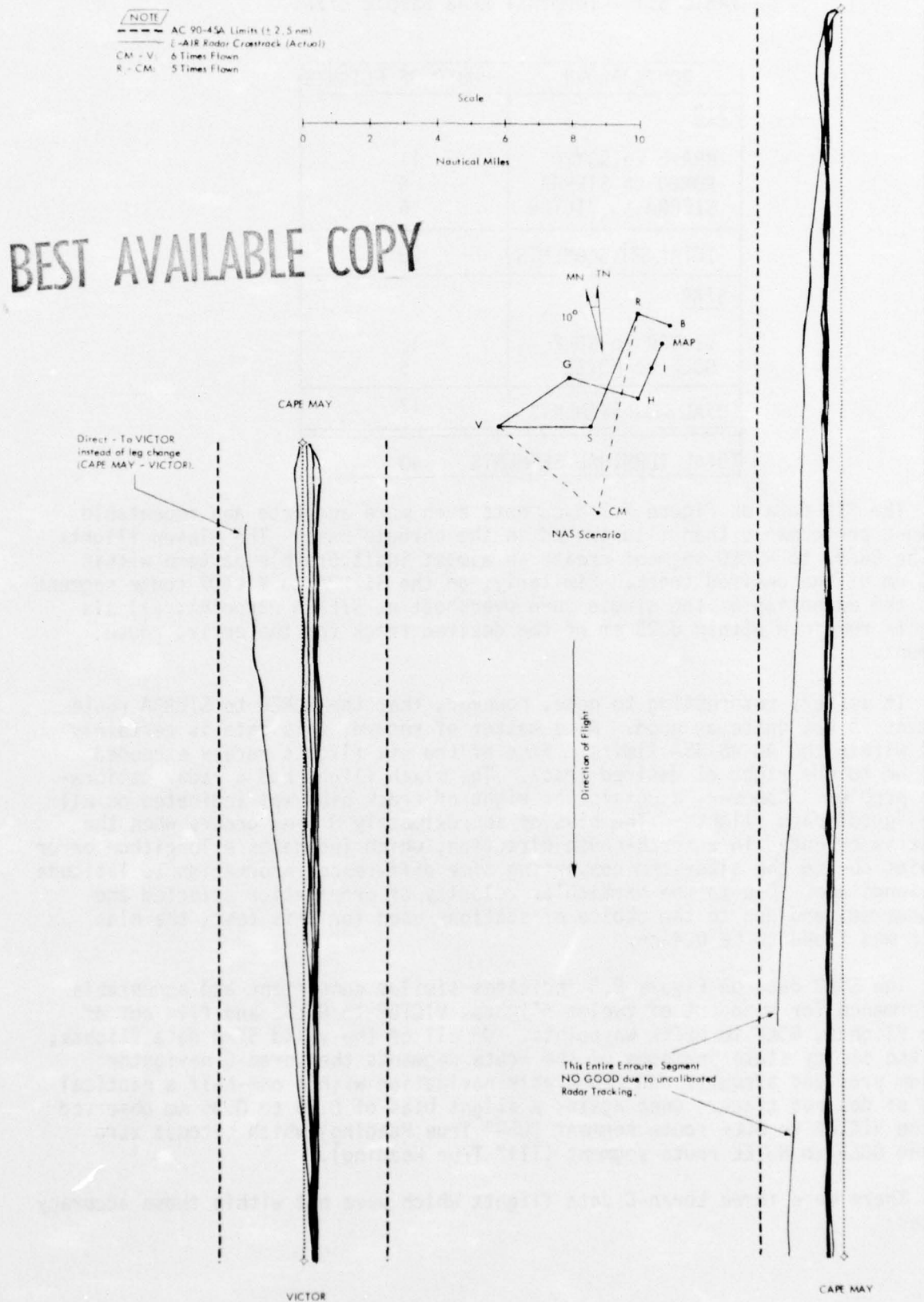


Table 5.1 Terminal Area Sample Sizes

ROUTE FLOWN	NUMBER OF FLIGHTS
<u>SID</u>	
BRAVO to ROMEO	11
ROMEO to SIERRA	6
SIERRA to VICTOR	6
TOTAL SID SEGMENTS	23
<u>STAR</u>	
VICTOR to GOLF	12
GOLF to HOTEL	5
TOTAL STAR SEGMENTS	17
TOTAL TERMINAL SEGMENTS	40

The SID data on Figure 5.2 documents even more accurate and repeatable Loran-C performance than illustrated in the enroute case. The eleven flights on the BRAVO to ROMEO segment create an almost indiscernible pattern within 0.25 nm of the desired track. Similarly, on the SIERRA to VICTOR route segment with the exception of the single turn overshoot at SIERRA waypoint, all six flights remained within 0.25 nm of the desired track for the entire route segment.

It is very interesting to note, however, that the ROMEO to SIERRA route segment is not quite as good. As a matter of record, this data is certainly well within the AC 90-45A limits. Five of the six flights rarely exceeded 0.75 nm to the right of desired track. The sixth flight had a radar calibration problem. However, a consistent right of track bias was indicated on all five "good" data flights. The bias of approximately 0.4 nm occurs when the track is oriented in a north-south direction, which indicates a longitude error or bias due to the algorithm converting time difference information to latitude and longitude. Due to the particular velocity of propagation selected and programmed, and due to the choice of stations used for this test, the bias error was found to be 0.4 nm.

The STAR data on Figure 5.3 indicates similar consistent and acceptable performance for nine out of twelve flights, VICTOR to GOLF, and five out of five flights, GOLF to HOTEL waypoints. On all of the valid STAR data flights, for the steady state portions of the route segments the Loran-C navigator system provided adequate and repeatable navigation within one-half a nautical mile of desired track. Once again, a slight bias of 0.25 to 0.35 nm observed on the VICTOR to GOLF route segment (059° True Heading) which becomes zero on the GOLF to HOTEL route segment (111° True Heading).

There were three Loran-C data flights which were not within those accuracy values:

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Figure 5.2 ATLANTIC CITY ONE RNAV SID
South Departure
Aircraft Flight Profiles
Terminal Area Segments

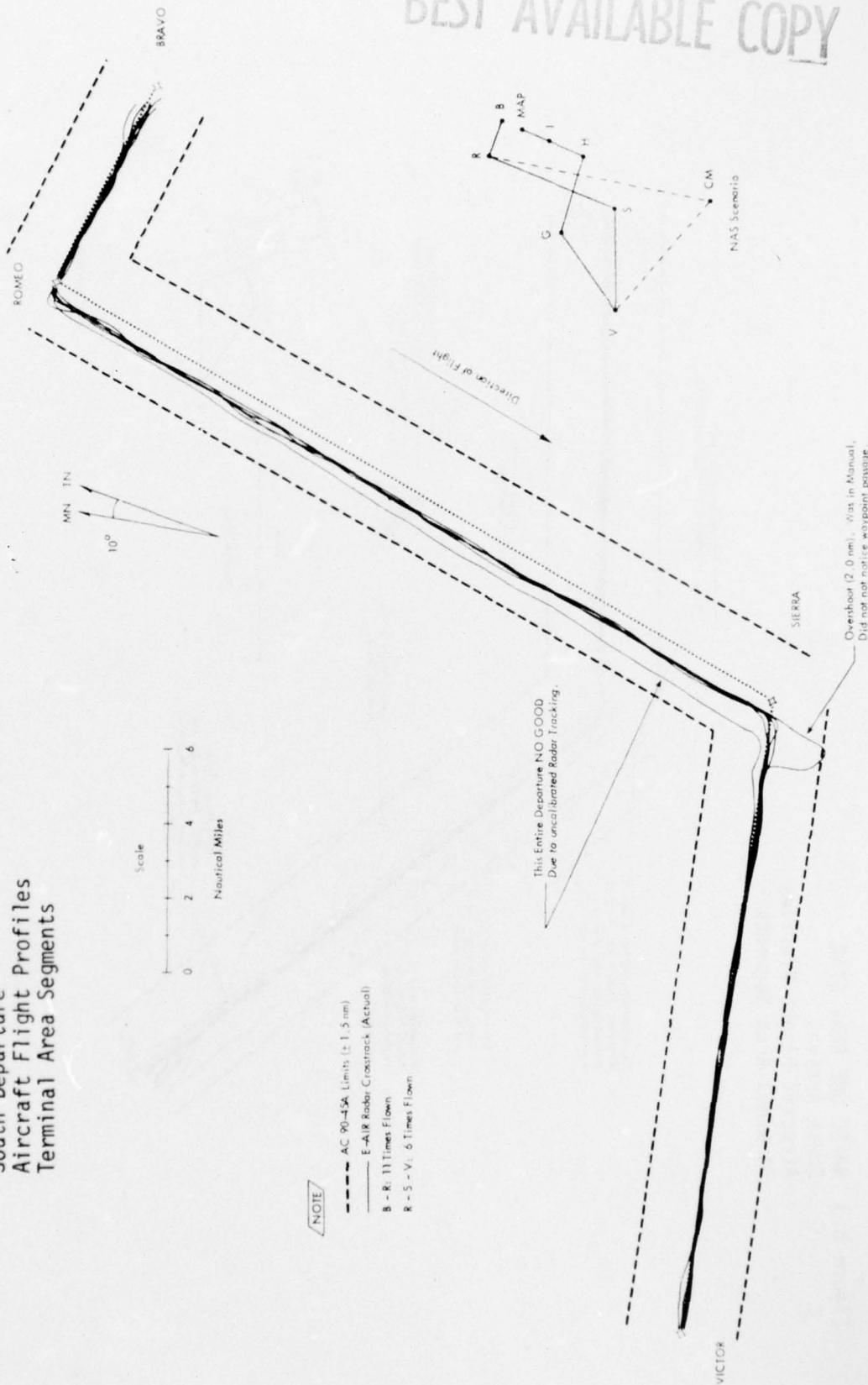
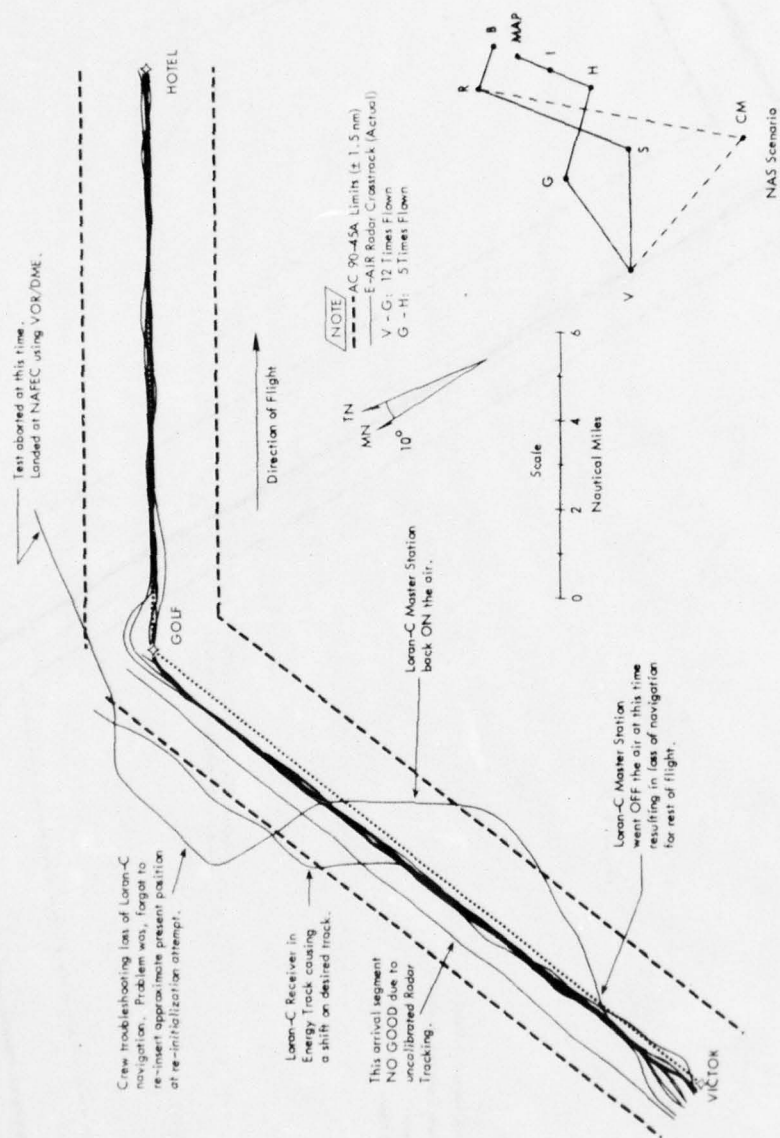


Figure 5.3 NAFEC ONE RNAV STAR
South Arrival
Aircraft Flight Profiles
Terminal Area Segments



- 1) The uncalibrated radar flight previously discussed.
- 2) A scheduled Loran-C master station shutdown occurred and the crew was not aided in resolving the navigator reinitialization procedures. (This is indicative of a typical training problem)
- 3) A Loran-C receiver problem occurred due to a shift in internal calculation of desired track which resulted in a fixed bias in the actual track. This calculation shift was not annunciated to the flight crew.

In summary, the terminal area maneuvering data obtained satisfactorily demonstrated track keeping accuracy for 37 of the 40 flights within the specified AC 90-45A limits (± 1.5 nm) for both STAR and SID routes.

5.1.3 Non-Precision Approach Analysis

Figure 5.4 summarizes the results of Loran-C final approach accuracy using three different modes of navigation waypoint input data. At the far left, plot (a), charted waypoint latitude/longitude data was input and the Loran-C navigator was updated pre-flight using the known position at the gate on Cape May Air Station. In the center, plot (b), charted waypoint lat/lon data was input without any initial system update. At the right, plot (c), measured waypoint data was input in time difference coordinates.

In the non-updated mode of operation, plot (b), the Loran-C navigator performed within ± 0.1 nm compared to the specified AC 90-45A limits of ± 0.6 nm except for a single flight where an equipment malfunction occurred. However, each of these uncalibrated flights indicated a consistent left of course bias of approximately 0.4 nautical miles. This is the same magnitude bias previously noted for both enroute and terminal testing. The magnitude of the bias becomes somewhat more significant in the final approach airspace. Arithmetically adding the bias to the two sigma gives a value of ± 0.48 nm which is close to the ± 0.6 nm limit. However, based on previous data reported in Reference 2, this final approach performance is no worse than other VOR/DME area navigation systems previously tested at NAFEC. As such, and since the AC 90-45A limits were not exceeded, the non-updated final approach mode is considered acceptable.

At the far left of the figure, plot (a), six approaches have been overlaid. These approaches were flown using charted waypoint latitude and longitude data with the navigator updated at the gate prior to take-off. As such, the waypoint data input was calibrated. The limits shown on this figure are consistent with AC 90-45A performance requirements of ± 0.6 nm. It can be seen that the Loran-C updated performance was always well within ± 0.6 nm of the desired final approach course. In fact, the actual performance was within ± 0.1 nm (see Table 5.2). A slight (approximately 0.1 nm) left of course bias was evident for all six updated flights. These final approach accuracies can be regarded as indicative of Loran-C capabilities over known final approach fixes such as would be common to a carrier at his home base or over a fixed route structure where frequent flights (approaches) were made over the same final approach waypoints such that the position update information would be both available and current. This would also be the case for a non-precision approach to an oil rig or platform.

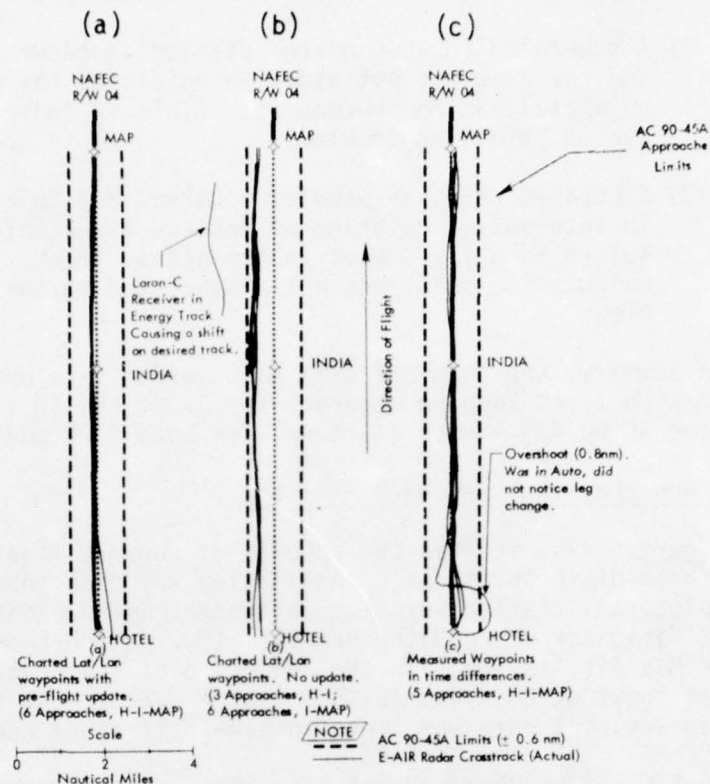


Figure 5.4 Final Approach Flight Profiles for Three Modes of Waypoint Input Data

Finally, the data on the right side, plot (c), of Figure 5.4 demonstrates Loran-C accuracy when operating in the time difference input mode. In this case, the bias shown in Figures (a) and (b) is completely eliminated. The track keeping accuracy is ± 0.12 nm and as such is significantly less than the ± 0.6 nm AC 90-45A limits. This is by far the most accurate and therefore the most desirable final approach operating mode. However, the time-differences which locate each waypoint must be known prior to flight in order to achieve this performance.

In summary, Loran-C performance data was collected using three different waypoint data input modes. These were:

- 1) Non-updated charted lat/lon input
- 2) Pre-flight updated lat/lon waypoint locations
- 3) Measured waypoint time difference inputs

The non-precision approach accuracy of the Loran-C navigator system was within AC 90-45A limits for all three input modes.

5.1.4 AC 90-45A Compliance Data

An AC 90-45A accuracy demonstration requires that specific total system and airborne error budget maximums are not exceeded for each of the three air-space regimes — enroute, terminal and approach. The design of this test program was intended to provide sufficient statistical results to satisfy these AC 90-45A requirements. Table 5.2 presents a summary of these results. The data recording and reduction procedures used during these tests provided a cross validation of the Loran-C system accuracy over and above the explicit AC 90-45A requirements. That is, the total system accuracy was measured directly using the NAFEC precision radar tracking facility in addition to calculating the total system accuracy as recommended in AC 90-45A using specified FTE values and measured airborne equipment errors. The latter technique was the procedure specified in AC 90-45A and reproduced as Equation (a) in Section 4.5.2. This equation simply computes the Root-Sum-Square (RSS) of measured airborne equipment error and the FTE specified in AC 90-45A, Appendix A, Paragraph 2.a(4) to document with a 95% confidence level that the two sigma total system cross track errors are not exceeded.

For the enroute case the measured TSCT error shown in Table 5.2 included a 0.10 nm bias and a ± 0.56 two sigma, which added together gives a worst case error of ± 0.66 nm, measured, compared with the 2.50 nm error tolerance specified. Furthermore, if the airborne equipment two sigma error of ± 0.57 is combined with the AC 90-45A specified ± 2.00 nm FTE using the RSS method, a calculated TSCT of ± 2.08 nm results, which is still acceptable. In fact, the measured airborne equipment error only affects calculated TSCT error in the second decimal (0.08) because of the large value of 2.00 nm specified for FTE.

For terminal area operations, Table 5.2 again illustrates satisfactory accuracy for Loran-C navigation. The measured TSCT was comprised of a negligible 0.03 nm bias and a two sigma of ± 0.51 . In comparison, the calculated TSCT using ± 0.49 measured airborne equipment error and the ± 1.00 FTE specified in AC 90-45A yielded an RSS value of ± 1.11 nm total system error. These values are all appreciably better than the ± 1.50 nm TSCT limit for terminal operations.

It is extremely important to note, however, that the measured FTE during these tests was ± 0.12 nm enroute, ± 0.15 nm terminal and from ± 0.05 nm to ± 0.14 nm in the approach case depending on the type of input data used to define the waypoints.

A pattern can be recognized in these two calculated results for enroute and terminal TSCT error. That is, the magnitude of the calculated TSCT closely follows (within 0.1 nm) the specified FTE. This is due to the consistently small two sigma airborne equipment error (± 0.57 nm enroute and ± 0.49 terminal), which when combined using the RSS method with an FTE of 1.0 or greater becomes almost insignificant.

The bias of the airborne equipment error for the terminal and enroute cases were ignored for two reasons. First, AC 90-45A assumes a zero bias and the calculations should be performed on a compatible basis. Second, the measured biases were considered small enough to be negligible (-0.10 nm enroute and -0.02 nm terminal) compared with the total limits of ± 2.50 nm and ± 1.50 nm for enroute and terminal respectively.

Table 5.2 Loran-C System Cross Track Accuracy vs AC 90-45A Compliance for Area Navigation Systems for Enroute, Terminal and Approach Phases (All Flights Combined)

	Measured ¹ Mean $\pm 2\sigma$ (nm)		Calculated Accuracy for Compliance ² $\pm 2\sigma$ (nm)	AC 90-45A $\pm 2\sigma$ (nm)
	Bias	$\pm 2\sigma$	$\pm 2\sigma$	$\pm 2\sigma$
<u>ENROUTE</u>				
TSCT	0.10	± 0.56	± 2.08	2.50
FTE	0.00	± 0.12	—	2.00
Airborne Equipment	-0.10	± 0.57	—	1.50 ³
<u>TERMINAL</u>				
TSCT	0.03	± 0.51	± 1.11	1.50
FTE	0.01	± 0.15	—	1.00
Airborne Equipment	-0.02	± 0.49	—	1.12 ³
<u>APPROACH (Non-updated L/λ)</u>				
TSCT	-0.38	± 0.10	(a) (b) $\pm 0.50/\pm 0.66$	0.60
FTE	0.02	± 0.09	—	0.50
Airborne Equipment	0.39	± 0.04	—	0.33 ³
<u>APPROACH (Updated L/λ)</u>				
TSCT	-0.07	± 0.06	± 0.50	0.60
FTE	0.00	± 0.05	—	0.50
Airborne Equipment	0.07	± 0.03	—	0.33 ³
<u>APPROACH (Time Difference)</u>				
TSCT	0.06	± 0.12	± 0.50	0.60
FTE	-0.01	± 0.14	—	0.50
Airborne Equipment	-0.07	± 0.05	—	0.33 ³

/Note/ ¹A negative sign means error to the right of course (fly left)

²Per AC 90-45A, Appendix A, Paragraphs 2.a(3) and 2.a(4)

³Implicit AC 90-45A airborne equipment error (maximum)

The final approach data were taken using three methods of waypoint input. First, charted latitude and longitude coordinates were used in a non-updated mode of operation. Second, charted latitude and longitude coordinates were input but the Loran-C position was updated using a known location prior to takeoff. Third, waypoint data was input using measured time difference coordinates. Table 5.2 summarizes all of these approach results.

Continuing the analysis ignoring bias errors results in meeting the AC 90-45A tolerance of ± 0.60 nm TSCT for all three waypoint data input modes. If measured airborne two sigma is RSS'd with the ± 0.5 nm FTE specified, then the calculated TSCT for all three modes equals ± 0.50 nm. This is attributed to the insignificant value of the airborne equipment error in these three cases (± 0.04 , ± 0.03 and ± 0.05 nm).

If measured TSCT is compared to the AC 90-45A limit of ± 0.60 nm, Loran-C accuracy is again satisfactory yielding values of ± 0.10 , ± 0.06 , and ± 0.12 nm for two sigma accuracy. This is attributed to the combination of the small airborne equipment error with an equally small measured FTE giving an extremely accurate TSCT.

The only problematical final approach data arises due to the bias error which was measured in the non-updated approach data. This bias error is known to be due to the constant Loran-C signal propagation velocity used in the software and has been discussed previously. Also, this bias would have decreased and a larger two sigma error calculated if many more approaches were flown to runways with headings which included the full range from 0-360°. However, these data were not taken and the airborne equipment bias is too large to be ignored (± 0.39 nm). Consequently, if the worst case is considered and the bias of ± 0.39 nm is added to the ± 0.04 nm two sigma, and this result (± 0.43 nm) is RSS'd with the ± 0.50 nm FTE specified, then the resultant calculated TSCT equals ± 0.66 nm, which does not satisfy the AC 90-45A tolerance of ± 0.60 nm (from Appendix A, paragraph 2.a(4)).

As already pointed out, this ± 0.66 nm number is somewhat misleading since the measured TSCT for the non-updated final approach data was only ± 0.48 nm including the bias. This is due to the fact that in the approach as well as in the enroute and terminal data, the measured FTE was on the order of 0.15 nm rather than the larger AC 90-45A specified values of 2.0 nm enroute, 1.0 nm terminal and 0.5 nm approach. This circumstance is adequately provided for in Appendix C of AC 90-45A which states in paragraph 6.b, "Error Budgeting":

"In establishing an error budget, a system designer may trade off reduction in the errors from one or more sources against increases in the errors from others. Thus, in adding an area navigation computing and display capability to the basic VOR/DME system, it is necessary and possible to compensate for the errors introduced by the new equipment by means of reductions in errors from other sources. Any of the airborne error elements, including Flight Technical Error, may be traded provided the total system accuracy reflected in Appendix D, Tables 2,3 and 4 are met."

The specific example which follows this paragraph in AC 90-45A, is for a VOR/DME system, but it explicitly illustrates the acceptability of reducing the specified FTE value in order to demonstrate compliance. In the case of the

Loran-C test data, it is strongly felt that FTE is always significantly less than the AC 90-45A specified value. Therefore, using this error budgeting trade off procedure along with the measured, non-updated approach FTE value of ± 0.09 nm is the correct and acceptable procedure. This procedure results in a calculated value of ± 0.50 nm for TSCT which validates the measured value (± 0.48 nm).

To summarize these results, for the non-updated approach data:

- 1) The measured bias plus two sigma TSCT is ± 0.48 nm which does not exceed the AC 90-45A tolerance of ± 0.60 nm.
- 2) The calculated RSS of measured FTE and measured airborne equipment error is ± 0.50 nm which does not exceed the ± 0.60 nm value.
- 3) Only the measured airborne equipment error (bias plus two sigma) combined using the RSS method with the specified AC 90-45A FTE error budget value of ± 0.5 nm exceeds the ± 0.60 nm TSCT limit. In this case Appendix C of AC 90-45A allows for reduction in the FTE budget value.

The overall analysis has shown that the Loran-C system tested satisfied AC 90-45A compliance criteria for enroute, terminal and approach. In fact, the Loran-C system tested falls well within the enroute and terminal error tolerances specified.

Table 5.3 is presented to provide additional detailed statistical results from the Loran-C flight test. This table lists statistical bias and two sigma error statistics by individual route segments showing TSCT, FTE and Airborne Equipment measured error budget data. This table also provides background information including the length of each segment, the statistical sample size or number of data points for each segment and the total number of segments flown. Finally, the segment statistics are aggregated into Enroute, SID, STAR, Terminal, L/ λ Non-Updated, L/ λ Updated and Time Difference Approach Data.

The enroute data on the CAPE MAY to VICTOR (325° magnetic course) route segment shows negligible bias or mean errors for TSCT, FTE and Airborne Equipment. This would be expected due to the large number of samples, 446. The two sigma error values are all acceptable on this segment. However, the ROMEO to CAPE MAY (206° magnetic course) shows significant bias errors in both the airborne equipment and TSCT. This bias is due to the utilization of the Dana station (large overland signal propagation) and the particular Loran-C signal propagation velocity stored in the TDL-424. Therefore, even with 366 data points, the combination of station, propagation velocity and course heading produced the significant bias error. Finally, when the two enroute segments are combined, the magnitude of the TSCT bias is reduced to ± 0.10 nm and the two sigma value is increased to ± 0.56 nm. This is precisely what would occur in reality if more enroute segments were flown at a multitude of course headings from $0-360^\circ$ even using the fixed propagation velocity and the Dana station. In summary, the enroute segment statistics are considered acceptable for all the data shown and flight within the AC 90-45A ± 2.50 nm limit was demonstrated.

Similar trade offs between bias errors and two sigma errors occur in the SID and STAR statistics. Note that a -0.24 nm bias occurs on VICTOR to GOLF and a $+0.41$ nm bias occurs on ROMEO to SIERRA. In each case, aggregation of all SID segments reduces this bias to $+0.16$ nm with an increased two sigma of

Table 5.3 Loran-C Flight Test Statistical Data Summary by Flight Segment

SEGMENT	TSCT		FTE		Airborne Equipment		Segment Length*	No. of Points	No. of Segments
	Bias	$\pm 2\sigma$	Bias	$\pm 2\sigma$					
	nm	nm	nm	nm	Bias nm	$\pm 2\sigma$ nm			
CAPE MAY-VICTOR	-0.13	0.25	0.01	0.13	0.14	0.26	24	446	5
ROMEO-CAPE MAY	0.39	0.12	-0.01	0.09	-0.40	0.09	37	366	4
<u>Enroute Aggregate</u>	0.10	0.56	0.00	0.12	-0.10	0.57	(30) avg	812	9
VICTOR-GOLF	-0.24	0.18	0.01	0.16	0.25	0.06	16	248	7
GOLF-HOTEL	-0.03	0.17	0.01	0.15	0.04	0.07	13	78	4
<u>STAR Aggregate</u>	-0.19	0.25	0.01	0.16	0.20	0.19	(15) avg	326	11
BRAVO-ROMEO	-0.08	0.18	0.02	0.18	0.10	0.03	6	147	7
ROMEO-SIERRA	0.41	0.14	0.01	0.13	-0.40	0.05	22	214	4
SIERRA-VICTOR	0.05	0.12	-0.01	0.10	-0.06	0.05	17	188	4
<u>SID Aggregate</u>	0.16	0.44	0.01	0.14	-0.15	0.42	(13) avg	549	15
<u>Terminal Aggregate</u>	0.03	0.51	0.01	0.15	-0.02	0.49	(14) avg	875	26
<u>Non-Updated Approach</u>									
HOTEL-INDIA	-0.37	0.11	0.02	0.09	0.39	0.04	6	57	3
INDIA-MAP	-0.39	0.09	0.01	0.09	0.40	0.03	5	36	4
<u>L/λ Non-Updated Aggregate</u>	-0.38	0.10	0.02	0.09	0.39	0.04	(5.4) avg	93	7
<u>Updated Approach</u>									
HOTEL-INDIA	-0.07	0.07	-0.01	0.06	0.07	0.03	6	55	5
INDIA-MAP	-0.07	0.04	-0.00	0.03	0.07	0.02	5	56	5
<u>L/λ Updated Aggregate</u>	-0.07	0.06	0.00	0.05	0.07	0.03	(5.5) avg	111	10
<u>Time Difference Approach</u>									
HOTEL-INDIA	0.06	0.16	-0.01	0.17	-0.07	0.05	6	32	5
INDIA-MAP	0.06	0.06	0.00	0.08	-0.06	0.04	5	26	4
<u>T/D Aggregate</u>	0.06	0.12	-0.01	0.14	-0.07	0.05	(5.6) avg	58	9

*/Note/ Average segment length indicated by () avg. was computed as a weighted average including the number of segments.

± 0.44 nm (average unaggregated two sigma was ± 0.15 nm). Similarly, the STAR aggregate data has a reduced bias of -0.19 nm and a two sigma of ± 0.25 nm.

In comparing the SID and STAR aggregate values it is seen that the SID performance was (0.16 ± 0.44) nm TSCT and STAR was (-0.19 ± 0.25) nm TSCT. The reason for the poorer SID performance was again a relatively long segment (ROMEO to SIERRA) with 214 data points on a magnetic course of 217° . This particular geometry produces the increased bias error which when combined with other segment statistics produces the larger two sigma. Finally, the combined SID and STAR performance resulted in a (0.03 ± 0.51) nm TSCT for all terminal operations compared to a ± 1.50 nm AC 90-45A error tolerance.

The final approach data has already been discussed in some detail. It is only necessary here to point out that the FTE values measured were all quite small and significantly less than the 0.50 nm AC 90-45A error budget value. Also, for two of the three waypoint input modes tested, the airborne equipment bias and two sigma errors were all less than 0.1 nm. Only the non-updated L/ λ input mode contained a rather large (-0.38 nm) bias error. Even in this case, however, the procedures outlined in AC 90-45A Appendix C were used to show that the TSCT tolerance of ± 0.6 nm was satisfied. Consequently, all approach data was considered acceptable and compliance with AC 90-45A was demonstrated.

5.1.5 NAS Procedural Compatibility

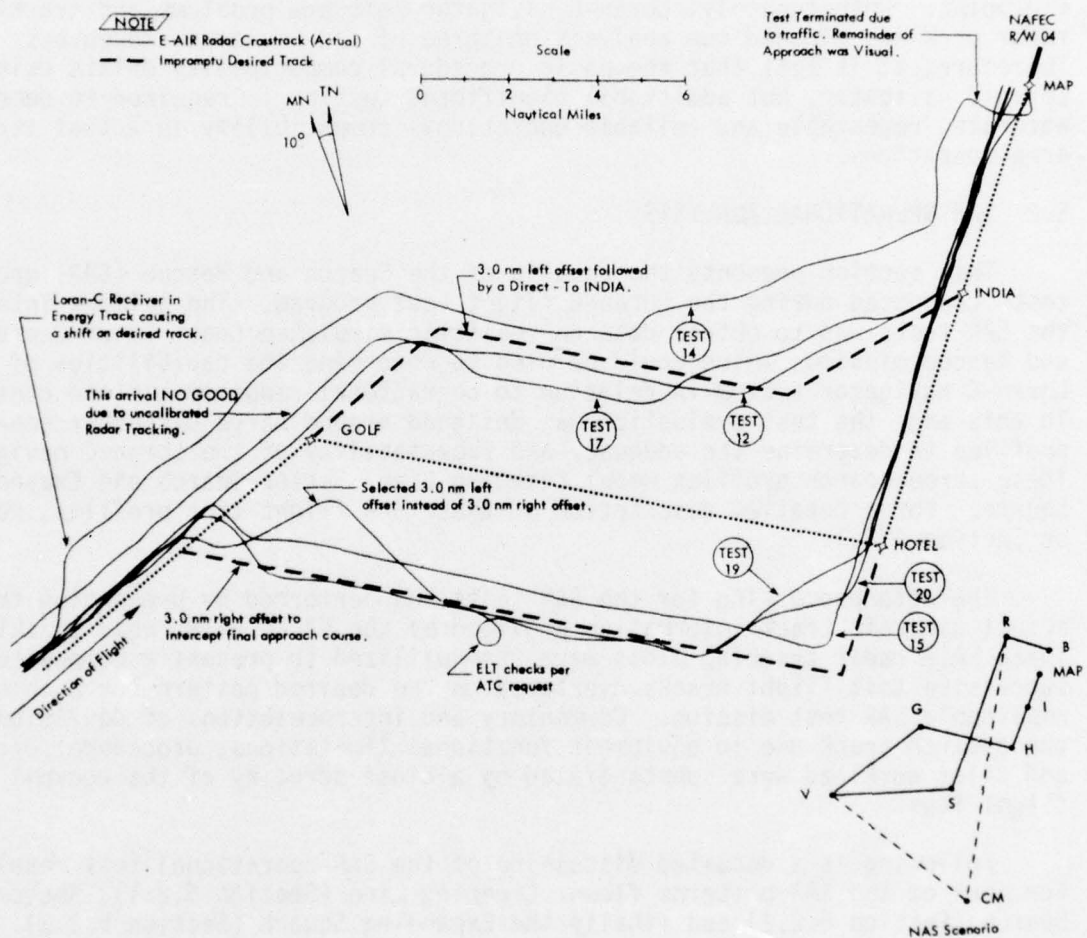
As an integral part of area navigation implementation, the RNAV FAA/Industry Task Force (Reference 3) developed airborne navigation procedures which were deemed necessary to transfer the desired navigation responsibility to the cockpit. Of the several procedures developed, two of the most important from an operational viewpoint are the "parallel offset" and the "direct-to" maneuvers. Both of these were tested in the region of the base leg during the Loran-C operational flight test.

Figure 5.5 presents the results from a three nautical mile right offset on base leg and a three nautical mile left offset terminated by a direct to INDIA command. The exact maneuvers and clearances issued for these impromptu maneuvers were presented in Section 4.2.

Of the three right offsets tested, two were successfully flown from the point of reclearance to within a few miles of the final approach course intercept. The third right offset was initially entered incorrectly as a left offset. However, once entered properly, the desired 3.0 nm right offset was flown adequately. A significant problem occurred in the interpretation of when and how this clearance should be terminated. Due to the software design of the Loran-C navigation (see Section 5.5), the displaced waypoint is not the same in both auto and manual modes. The 3.0 nm right offset was supposed to be maintained until intercepting the final approach course as was done on test 15. However, on flights 19 and 20, the pilot terminated the right offset prematurely and began navigating to HOTEL waypoint. There is nothing mechanically incorrect with this procedure, but it was not consistent with the clearance issued. This resulted in short-cutting the corner at base leg/final approach intercept by as much as three nautical miles and could possibly lead to interference with parallel base-leg traffic not on the offset course.

The three left offsets did not experience any significant problems in acquiring the proper track. This is due to the geometry tested where the offset could be reached by a simple extension of the VICTOR to GOLF (present) route segment. This maneuver is representative of extended downwind legs. Although

Figure 5.5 NAFEC ONE RNAV STAR SOUTH ARRIVAL AIRCRAFT
FLIGHT PROFILES WITH IMPROMPTU OFFSETS



some tracking accuracy problems (Test 12) and a Loran-C receiver problem (Test 14) were experienced, the available data indicates satisfactory performance during the stable portion of the three nautical mile left offset on the base leg. Similarly, the "Proceed Direct To INDIA" ATC command was apparently adequately performed in at least two of the three cases tested. However, due to the problems indicated it was felt that no viable conclusions could be drawn from these data.

In summary, an attempt was made to perform two meaningful and important impromptu ATC maneuvers. These were the parallel offset and the direct to maneuvers. The area where these impromptu commands were given was on the base leg where a fairly substantial pilot workload already exists. Nevertheless, the maneuvers were apparently performed satisfactorily from an operational viewpoint. Unfortunately, Loran-C navigator software problems and tracking radar problems clouded the analysis on three of six impromptu maneuvers. Therefore, it is felt that the basic procedural compatibility exists using the Loran-C navigator, but additional significant testing is required to demonstrate accurate, repeatable and reliable operational compatibility in actual terminal area operations.

5.2 SAR OPERATIONAL ANALYSIS

This section presents the results of the Search and Rescue (SAR) operational tests conducted during the Loran-C flight test program. The primary intent of the SAR tests was to obtain data on realistic simulated Coast Guard Search and Rescue missions which could be used to determine the capabilities of the Loran-C navigator system in relation to operational requirements and constraints. To this end, the test evaluation was designed around three different search profiles to determine the adequacy and repeatability of the Loran-C navigator. These three search profiles were: Creeping Line, Sector Search and Expanding Square. For a detailed description of these SAR flight test profiles, refer to Section 4.2.1.

The data processing for the SAR tests was performed by presenting the actual aircraft track information provided by the NAFEC EAIR radar tracking plots. These EAIR radar tracking plots were then utilized to present a composite of successive test flight tracks overlayed on the desired pattern for each of the applicable SAR test mission. Commentary and interpretations of deviations from the desired track due to equipment functional limitations, procedural errors and pilot workload were substantiated by a close scrutiny of the cockpit observer flight logs.

Following is a detailed discussion of the SAR operational test results for each of the SAR patterns flown: Creeping Line (Section 5.2.1); Sector Search (Section 5.2.2) and finally the Expanding Square (Section 5.2.3).

5.2.1 Creeping Line Pattern

Excellent results were achieved by the utilization of the Loran-C navigator in the execution of the Creeping Line pattern. The Loran-C navigator provided the pilot the ability to effectively maintain desired track spacing and sweep width throughout each of the Creeping Line patterns flown. The repeatability of the Loran-C navigator in providing accurate navigation to the pilot is evidenced by an inspection of Figure 5.6(a). This figure shows all the Creeping Line patterns flown (5) by the subject pilots, utilizing the Loran-C navigator. The

Figure 5.6 Loran-C SAR Operational Tests
Creeping Line Patterns (Actual Crosstrack, Composite)

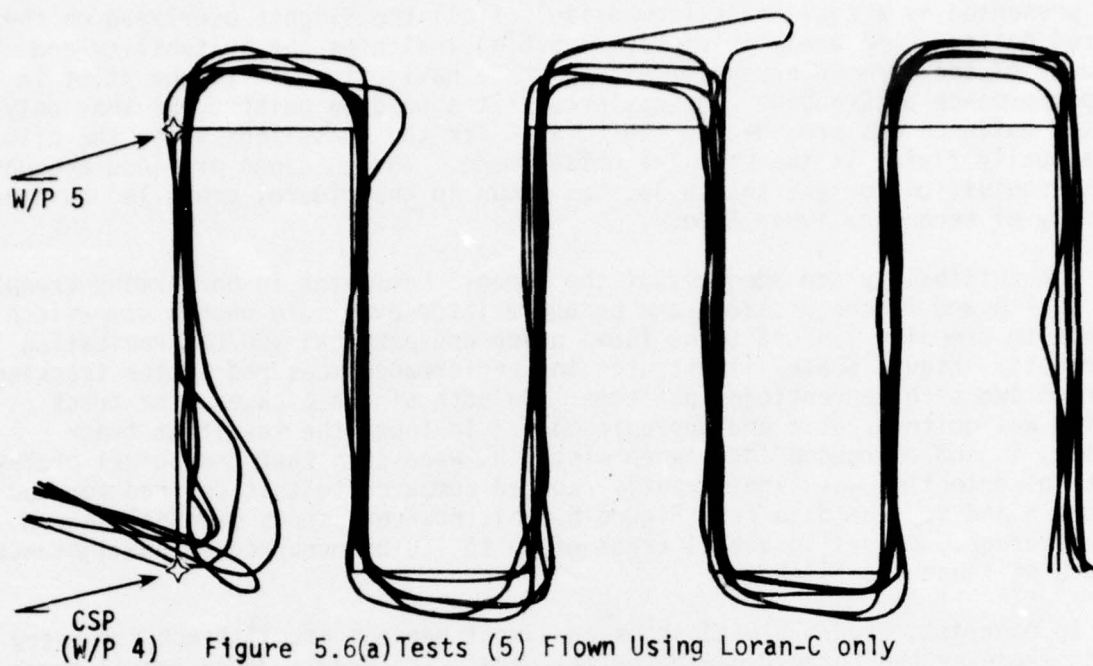


Figure 5.6(a) Tests (5) Flown Using Loran-C only
Offsets of 2L, 4R, 6L, 8R and 10L from baseleg

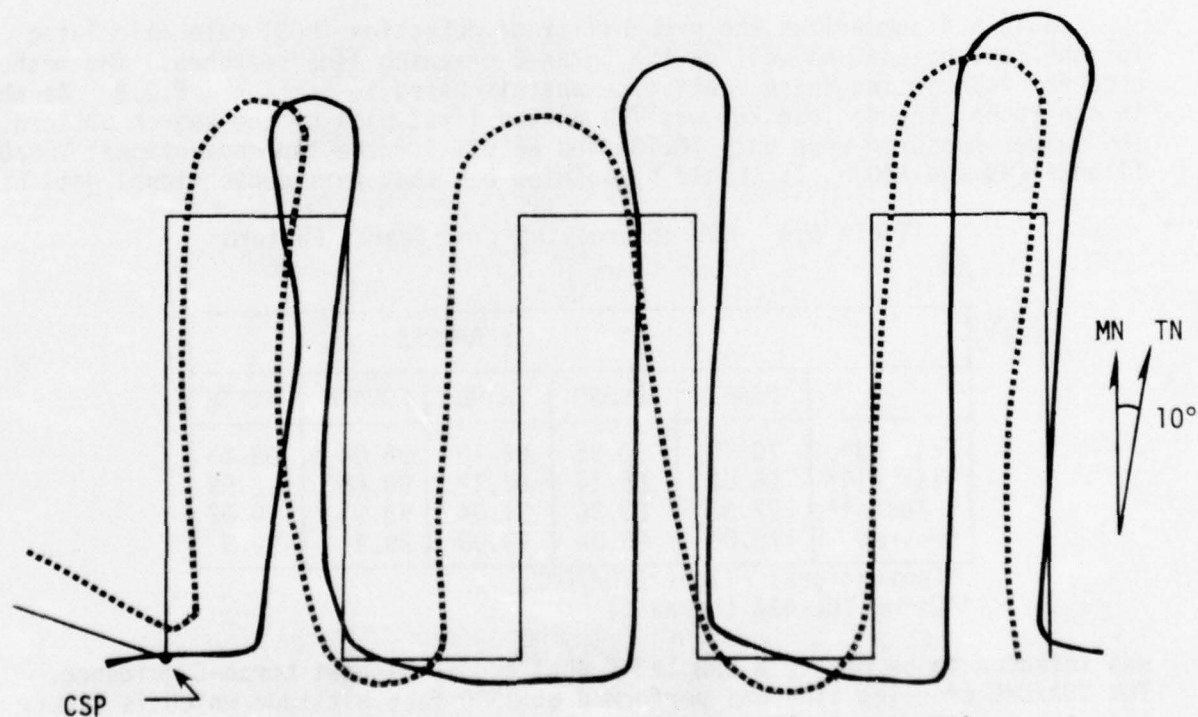


Figure 5.6(b) Tests (2) Flown Using VOR/DME only (W/O Loran-C)

Scale
0 2
Nautical Miles

data presented is actual track (composite) of all the flights overlayed on the desired pattern. An analysis of Figure 5.6(a) indicates the suitability and adequacy of the Loran-C navigator as a precise navigation aid to the pilot in the performance of Creeping Line patterns. It should be pointed out that only limited guidance was provided by the Loran-C for the cross-legs since the pilot was actually flying in the parallel offset mode. The guidance provided adequate track acquisition for the search legs as shown in the figure, cross leg guidance was only of secondary importance.

The suitability and adequacy of the Loran-C navigator in performing creeping line search and rescue missions can be appreciated even more when a comparison is made to creeping line patterns flown using conventional VOR/DME navigation techniques. Figure 5.6(b) illustrates the performance measured by the tracking radar on two such conventional patterns. In both of these cases, the track spacing was quite erratic and unpredictable. In fact, the resultant track spacing, S, and corresponding sweep width, W, were such that the actual probability of detection was significantly reduced compared to that desired for the planned S and W. The data from Figure 5.6(b), however, shows marginal search area coverage. Errors in actual track of up to 1.0 nm occurred in one instance on each of these two flights.

In contrast, Figure 5.6(a) shows an almost perfect actual track for every flight whenever the Loran-C navigator was used. The magnitude of actual cross track error from desired using the Loran-C navigator was approximately 0.2 nm and uniformly distributed along each leg.

Table 5.4 summarizes the probability of detection (POD) data calculated for the conventional as well as the Loran-C creeping line searches. The method used for calculating these statistics was discussed in Section 4.5.2.B. As shown in the table, the desired POD was 78% on the first pass of the search pattern. The values measured were only 70.10% and 66.63% for the two conventional VOR/DME flights (#9 and #10). It should be pointed out that this conventional data base

Table 5.4 POD of Creeping Line Search Patterns

SEARCHES					
	FIRST	SECOND	THIRD	FOURTH	FIFTH
Test #9*	70.10	90.95	95.18	98.04	98.83
Test #10*	66.63	85.14	92.17	96.68	98.59
5 Tests**	77.33	93.96	97.94	98.91	99.02
Desired	78.00	95.00	99.00	99.9	99.9

*Conventional Flight (VOR/DME)

**Using TDL-424 (Loran-C)

was intended to be merely a sample of what occurs without Loran-C guidance. The VOR/DME creeping line was performed at 2500 feet altitude, which is higher than the normal search altitude. This fact had two effects on the data collected. First, the flight path or creeping line pattern might have been better at the lower altitude at which searches are normally performed since it is easier for the pilot to estimate drift at these lower altitudes. Second, it is doubtful that VOR/DME could have been received at the lower altitudes and in this case

the flight path accuracy would be degraded. For these two reasons, the POD statistics in the conventional VOR/DME navigation mode should be considered to have limited applicability to the general creeping line search case in the non-navigator mode (i.e., without Loran-C).

For comparison with the Loran-C POD values, the two conventional VOR/DME POD's may be averaged to yield a 68.4% POD on the first pass. In contrast, the Loran-C navigator increased the POD to 77.33% on the first pass. This is very close to the desired 78.00%. The conventional flights indicate that 1.4 searches or 1.6 searches would be required to achieve the 78.00% POD depending on whether flight 9 or 10 data is interpolated. It can be concluded, then, that the Loran-C increased search effectiveness by an average increase of 8.9% POD on the first pass (77.3-68.4) or that the number of passes required to achieve 78.00% POD was reduced from 1.5 using conventional VOR/DME navigation to 1.04 using the Loran-C navigator. This is a 31% reduction in the number of searches required to achieve a 78.00% POD.

The execution of the creeping line pattern utilizing the Loran-C navigator required the use of the set of parallel track features indicated on Figure 5.6(a). Since there were 6 legs to be flown at 2.0 nm track spacing, 3 left offsets of 2.0 nm, 6.0 nm and 10.0 nm and 2 right offsets of 4.0 nm and 8.0 nm were required. All the legs were 5.0 nm long. The test procedure utilized by the subject pilots for the execution of the creeping line was to select the referenced waypoints (W/P 4 and W/P 5) of the initial leg in the proper order and to enter the required offset. This was performed at the end of each leg, and on the average required approximately 10 seconds. The desired leg change and appropriate offset input was always performed by the copilot. Concurrently, the pilot would turn the aircraft towards the next leg to be flown and once the required navigator entry sequence was completed, the pilot would resume monitoring CDI/DTW indications to intercept the desired track of next leg.

The incorporation of the Loran-C navigator does not seem to increase the level of workload as an added flight instrument to the normal crew's cockpit workload during the execution of the creeping line pattern. As previously discussed the required manual input time to completely prepare for the next leg was generally only 10 seconds. However, there were a few instances in which the crew became confused regarding which leg of the over-all creeping line pattern they were on or the magnitude of the offset to be entered and whether a left or right offset was required. This information was not provided by the Loran-C navigator, but rather the crew was required to do the necessary planning and come to a decision regarding which data was to be entered next in the Loran-C navigator.

During the SAR operational tests conducted in the Loran-C test program, every effort was made to simulate a real SAR mission and the corresponding workload, however, the crew did not have to look for any targets and only one type of creeping line pattern was flown (one combination of W and S). Nevertheless, a total of 5 blunders, all pilot initiated, were recorded during the creeping line pattern tests. All of these blunders were considered minor and judged to not have affected the overall SAR mission performance. These particular blunders are discussed in detail in Section 5.4 (Blunder Items 6, 7, 8, 9 and 16).

The fact that minor blunders of this type were committed was not surprising since the SAR missions were deliberately flown prior to the NAS flights in order to provide additional Loran-C training and familiarity. Also, it is important to note that once these initial SAR flights were completed, the number of blunders was significantly reduced during the NAS flights. This would be expected due to the normal learning curve associated with the navigation task being tested.

To summarize, it is felt that the Loran-C navigator in its present configuration will be a valuable tool to the SAR crew in the execution of the Creeping Line patterns. However, it is also considered important that the addition of programmable selected features to the Loran-C navigator could significantly improve its effectiveness during SAR type missions. For example, the ability to program any given Creeping Line pattern so that the pilot would simply have to fly the indicated track would reduce pilot workload and consequently reduce the chance for blunders. This would also eliminate the present requirement to provide manual data entries at the end of each leg and consequently the SAR crew would have considerably less workload and could concentrate on aircraft safety and the primary objective of the mission, which is to find the target.

5.2.2 Sector Search Pattern

The acceptability of the Loran-C navigator in assisting the SAR crew to execute a Sector Search Pattern was judged to be adequate. A total of four sector search patterns were flown, utilizing the Loran-C navigator during the SAR operational tests. The planned number of sector search patterns was six, but due to equipment and schedule problems, two of these were cancelled. Although the data sample was smaller than anticipated, the accuracy and repeatability of the Loran-C navigator tested allows substantial qualitative conclusions.

The sector search testing included performing two sector search patterns without using the Loran-C navigator and relying solely on conventional DR techniques using a smoke flare to mark datum. The purpose of these two tests was to obtain baseline data (SAR conventional technique) from which the sector search patterns that were executed utilizing the Loran-C navigator could be evaluated.

The sector search pattern consisted of flying 6 legs, each 4.0 nm long through the datum and 5 cross-legs at a 30° central angle. The test procedure was initiated by the subject pilots for the execution of the sector search pattern by defining the datum as waypoint No. 7 (see Figure 5.7a). The first leg of the sector search pattern after having crossed datum was defined by leg (7-8). This first leg was defined to assure that all sector search patterns would be flown in the same direction and thus be evaluated for repeatability. Once the first leg was flown, the aircraft was turned clockwise to intercept the beginning of the next leg. The new leg intercept was determined by monitoring the bearing changes to waypoint 7 (datum) on a new selected leg (from present position (waypoint 0) to datum (waypoint 7)). During the turn to intercept the beginning of the next leg, the distance to waypoint indications on the Loran-C navigator were also monitored to indicate interception of the proper leg length (2.0 nm) to the datum. Once the desired leg intercept was accomplished, a new leg (0-7) was defined. The aircraft then proceeded "TO" datum. When datum was passed, the remainder of the leg (2.0 nm) was flown in the "FROM" mode.

Figure 5.7 Loran-C SAR Operational Tests
Sector Search Patterns (Actual Crosstrack)

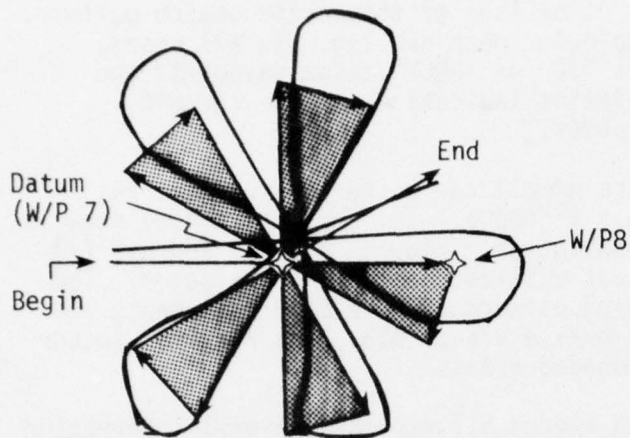


Figure 5.7(a)*

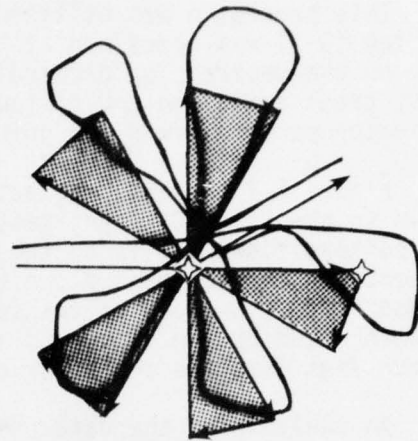


Figure 5.7(b)*

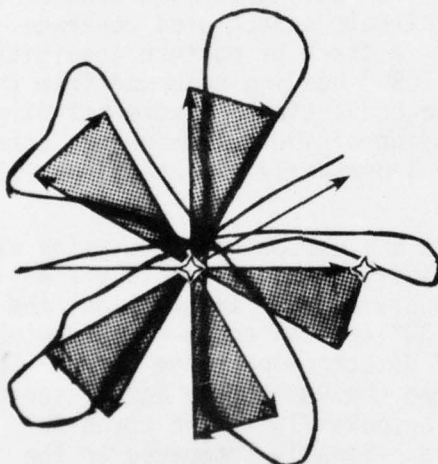


Figure 5.7(c)*

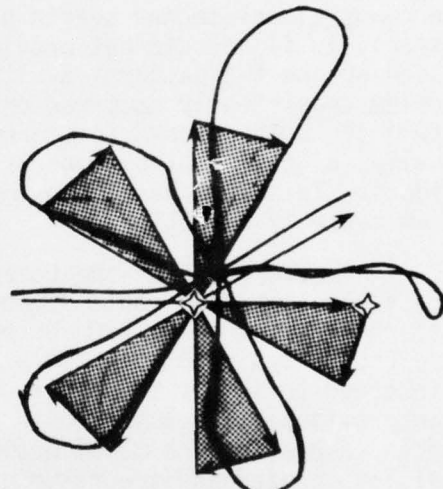


Figure 5.7(d)*

Scale
0 2
Nautical Miles

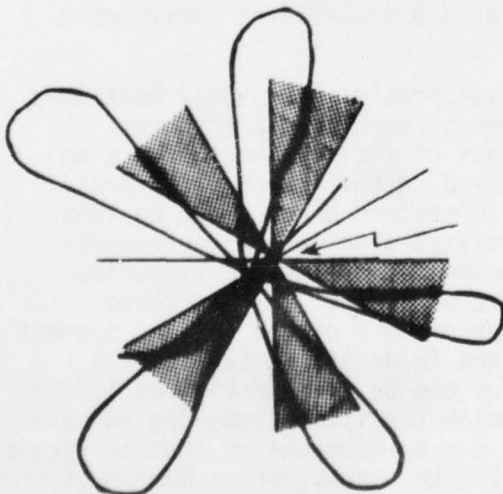


Figure 5.7(e)**

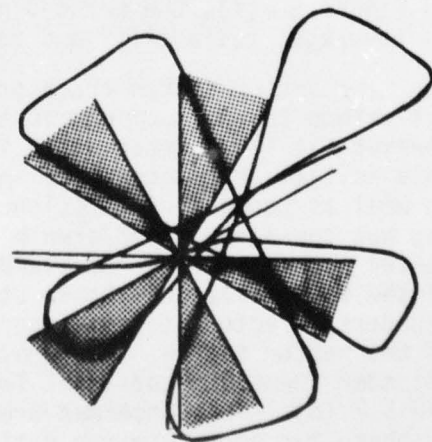


Figure 5.7(f)**

Note:

- * Test Flown Using Loran-C only
- ** Test Flown Using VOR/DME only (W/O Loran-C)

This procedure was utilized for the other legs of the sector search pattern. The leg (0-7) was redefined at the beginning of each new leg. In all cases, when on the desired leg proceeding either "TO" or "FROM" datum waypoint, the cross track deviation and distance to waypoint indications of the Loran-C navigator were followed for guidance purposes.

Figure 5.7 presents the actual tracks of all the sector search patterns flown in the Loran-C flight test program. Figure 5.7 (a) through 5.7 (d) show the pattern flown utilizing the Loran-C navigator. Figures 5.7 (e) and 5.7 (f) present the two patterns flown that did not utilize the Loran-C navigator. The shaded portion on each of the sector search pattern (Figure 5.7) represents the area enclosed by the legs, and is provided as a visual aid. The required sector search legs form the perimeter of these shaded areas.

An analysis of the data presented on Figure 5.7 provides several interesting results. First, all sector search patterns flown using the Loran-C navigator (Figures 5.7 a,b,c,d) were sufficiently close to the desired pattern. Second, the conventional sector search patterns (Figures 5.7 e,f) were much more erratic (especially f) and did not provide adequately reliable search area coverage (based on the two patterns available). Thirdly, a track or pattern acquisition problem consistently occurred on the first leg (090° heading outbound from the datum) for both Loran-C (patterns b,c,d) and the conventional (patterns) flights. Finally, a consistent bias occurred in the location of the datum for the Loran-C flights. This bias was approximately 0.4 nm in a northerly direction and 0.2 nm in an easterly direction.

The performance of the Loran-C navigator on the sector search mission was acceptable since the route segments flown were sufficiently close to the desired pattern except for the 090° outbound leg previously noted. In addition, the five cross-legs were adequately spaced and the 30° central angle was acceptably maintained to insure the desired probability of detection near the datum. The bias previously discussed would not have affected the POD in the actual sector search case since the datum would be marked by a smoke flare, the Loran-C position updated and the datum precisely defined. Finally, compared to the conventional pattern shown in Figure 5.7(e), the performance of the Loran-C navigator was at least as good, and compared to the conventional pattern shown in Figure 5.7(f), the Loran-C navigator demonstrated a significant improvement in coverage, reliability and repeatability.

The sector search track or pattern acquisition problem previously mentioned was unique to this experiment and directly related to specified procedures. However, it is interesting to investigate the cause of the poor performance on this initial leg since it definitely impacts desired sector search procedures as well as Loran-C utilization. The sector search pattern degradation on this leg was caused by pilot/crew blunder errors associated with the unique experimental procedures. Three blunder errors were documented during the execution of the sector search pattern utilizing the Loran-C navigator. All of these blunders affected, to some degree, the overall performance of the initial segment of the sector search. These blunders are discussed in detail in Section 5.4 (Blunder Items 2,3 and 19). Two of these blunders can be seen in Figures 5.7 (c) and 5.7 (d). The concerned area is the execution of the first cross-leg on each of these two sector search patterns which caused a poor coverage of that particular sector. These two blunder errors, which were pilot-initiated, are a byproduct of a required flight test procedure to perform the sector search patterns. In designing the sector search pattern an additional waypoint was added at the end of the first leg (2.0 nm after having crossed datum). The idea was that by in-putting the waypoint all pilots would be forced to fly the sector search pattern

in the same direction, regardless of wind conditions, so that the resulting tracks could be overlayed on successive flights and thus be evaluated for repeatability. It was the use of this added waypoint which confused this particular crew (subject pilots C & D alternated as pilot/copilot on both of these flights). The crew performed their initial cross leg based on a bearing to waypoint 8 (specially added) instead of the waypoint 7 (datum). In practice, only one waypoint (datum) is actually required by the Loran-C navigator as a data entry in order for the pilot to execute a SAR sector search pattern. The other blunder error recorded was due to an equipment malfunction (see discussion on blunder Item 19). Its effect can be observed on Figure 5.7(b), while the crew was attempting to perform the initial cross-leg of the sector search pattern.

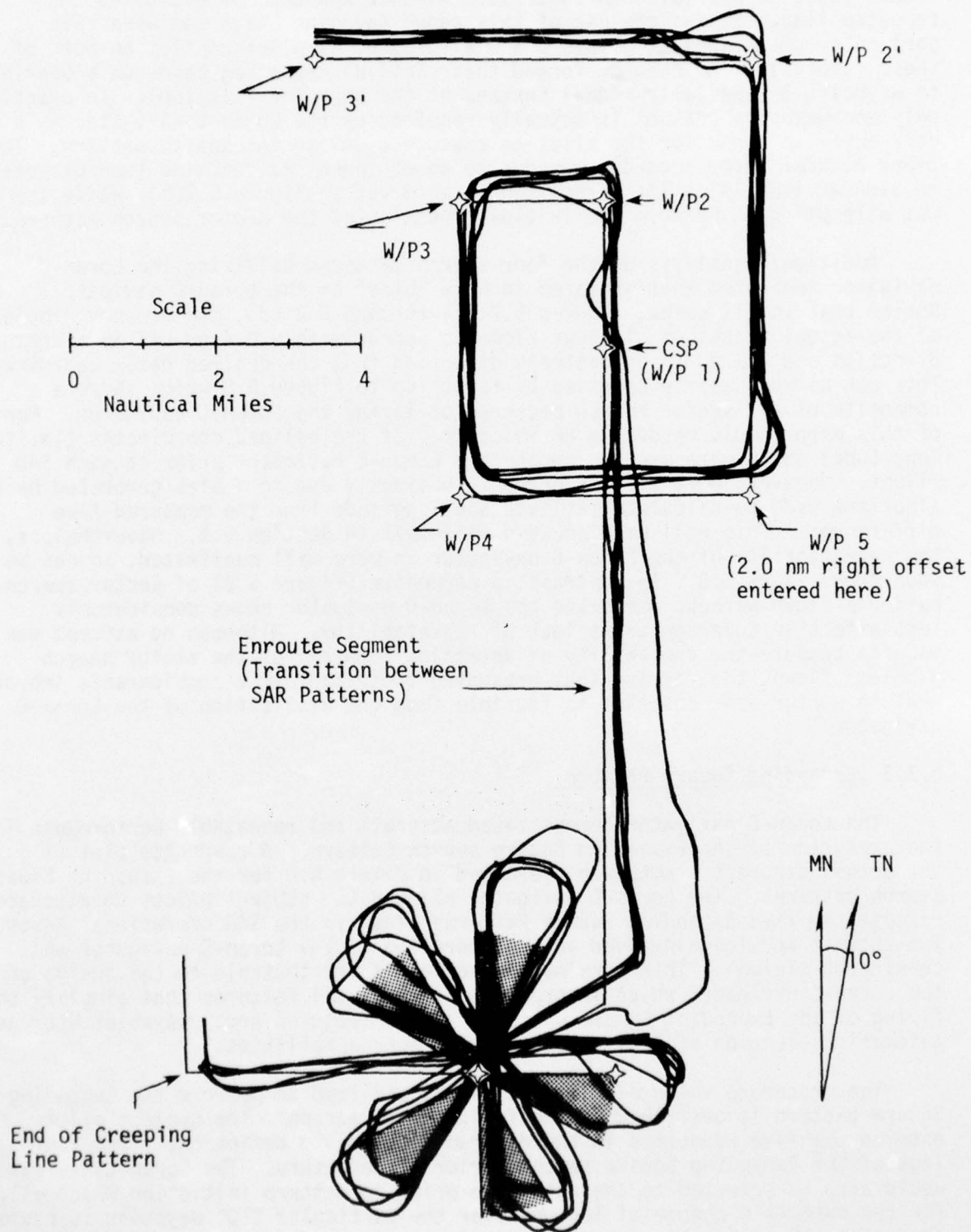
Additional analysis of the four search patterns utilizing the Loran-C navigator indicated what appeared to be a "bias" on the Loran-C navigator. Notice that in all cases, Figures 5.7 (a) through 5.7 (d), the crossover point of the actual tracks of all legs flown is approximately 0.4 nm off in a northerly direction and 0.2 nm in an easterly direction from the desired datum coordinates. This can be more easily assessed by referring to Figure 5.8 which shows a composite of all sector search patterns utilizing the Loran-C navigator. Part of this error could be due to an inaccuracy of the helipad coordinates (latitude/longitude) which were used to update the Loran-C navigator prior to each SAR flight. However, part of this error is obviously due to a bias generated by the algorithm used to calculate latitude and longitude from the measured time differences. This will be discussed in detail in Section 5.5. Nevertheless, the repeatability of the Loran-C navigator is very well manifested, as can be seen from Figure 5.8. In contrast, a composite (Figure 5.9) of sector search patterns flown without utilizing the Loran-C navigator shows considerably less effective coverage and a lack of repeatability. Although no attempt was made to compute the probability of detection from all of the sector search problems flown, the results thus presented indicate that a considerable improvement in sector area coverage is feasible from the utilization of the Loran-C navigator.

5.2.3 Expanding Square Pattern

The Loran-C navigator demonstrated accurate and repeatable performance in the execution of the Expanding Square search pattern. A composite plot of the actual aircraft tracks was presented in Figure 5.8 for the Expanding Square search patterns. The Loran-C navigator allowed the subject pilots to accurately execute the five Expanding Square Patterns flown in the SAR operational tests. The cockpit workload involved in the operation of the Loran-C navigator was considered minimal. This workload reduction is attributable to the design of the Loran-C navigator which incorporated operational features that simplify the flying of the Expanding Square pattern. These features are: waypoint storage, automatic selection of legs and parallel track capabilities.

The procedure which all subject pilots utilized to perform the Expanding Square pattern is described in the following paragraph. The subject pilots entered the five waypoints in the desired sequence to define the first four legs of the Expanding Square pattern prior to departure. The Loran-C navigator would also be selected to the auto mode prior to pattern initiation which allows for the automatic change of leg whenever the particular "TO" waypoint is passed. The pilot then flew the aircraft according to the Loran-C driven NFDI and distance to waypoint indications. At the end of the fourth leg, the crew selected the required 2.0 nm right offset and then reselected (manually) the initial leg

Figure 5.8 Loran-C SAR Operational Tests
Sector Search* and Expanding Square** Patterns
Actual Crosstrack Composite

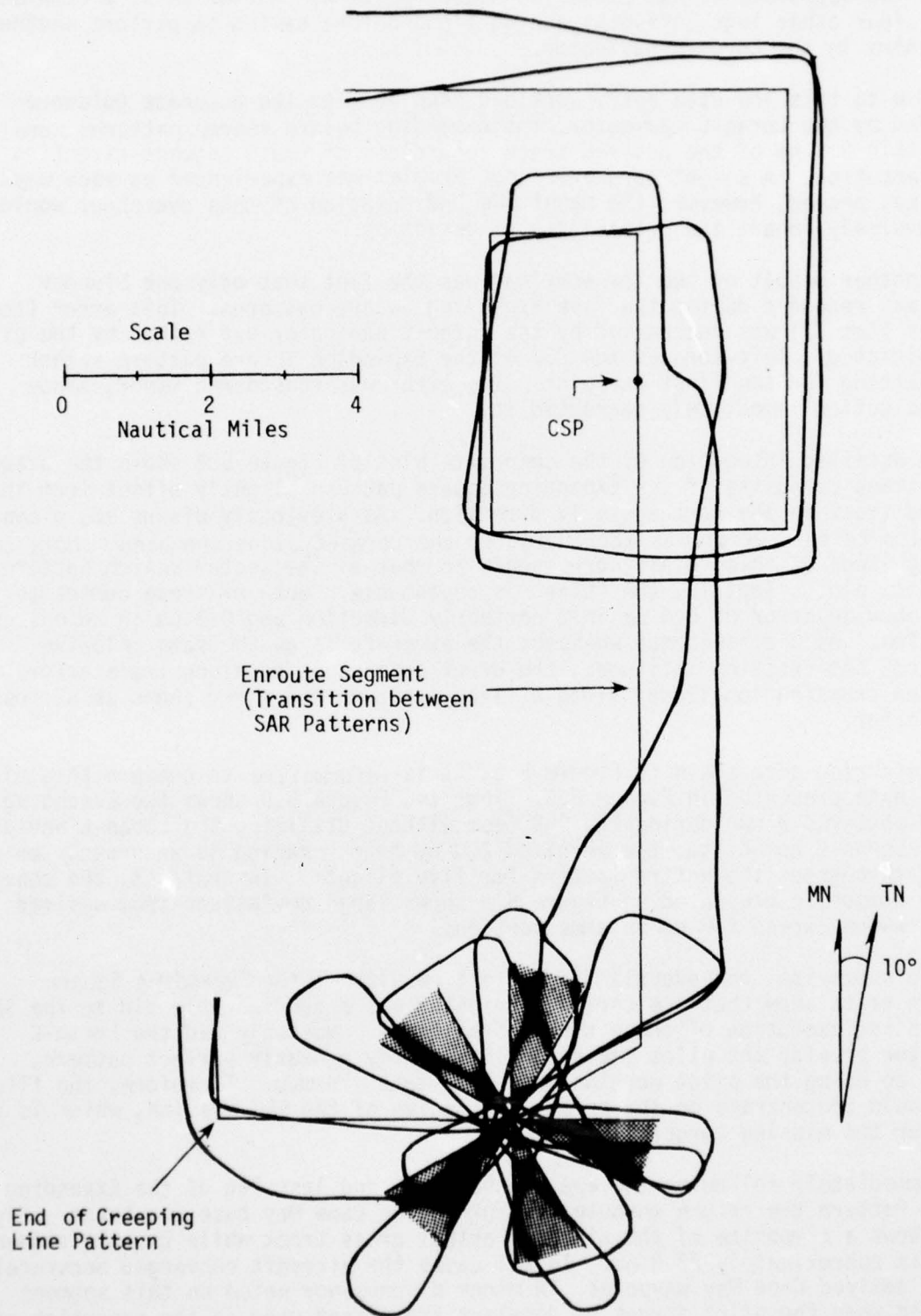


Note:

* Total of 4 patterns flown

** Total of 5 patterns flown

Figure 5.9 Loran-C SAR Operational Tests
 Sector Search and Expanding Square Patterns* Using only
 VOR/DME and Without Loran-C Actual Crosstrack Composite



Note:

*Total of 2 patterns flown

(first two waypoints of the Expanding Square pattern). After this, a complete set of four other legs (offsets) can be flown before having to perform another data entry in the Loran-C navigator.

Due to this low data entry workload coupled with the accurate guidance provided by the Loran-C navigator, the Expanding Square search patterns were all within 0.4 nm of the desired track regardless of route segment direction or orientation. A slight turn overshoot problem was experienced as each waypoint was passed, however, the magnitude and duration of this overshoot would not adversely impact the probability of detection.

Another result of the low workload was the fact that only one blunder error was recorded during the five Expanding Square patterns. This error (see Blunder Item 17) was not caused by the Loran-C navigator but rather by the pilot who initiated a left turn at the CSP of the Expanding Square pattern rather than waiting for the first waypoint. The error was considered minor, since copilot action immediately corrected it.

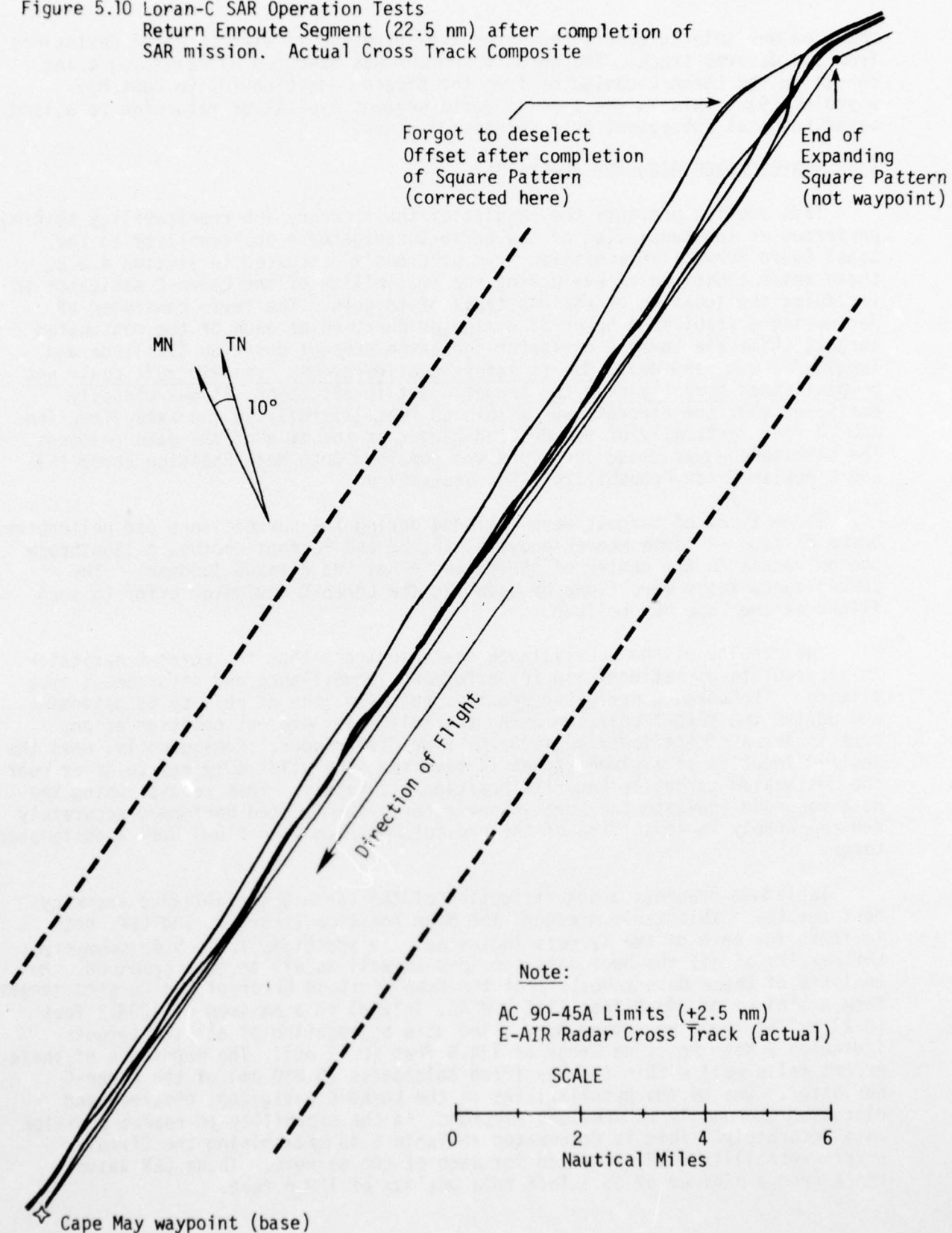
A detailed inspection of the composite plot of Figure 5.8 shows the actual cross track composite of the Expanding Square pattern slightly offset from the desired track in the northeasterly direction. As previously discussed, a contribution to this error was attributed to the Loran-C algorithm used. Note that the magnitude of this "bias" corresponds to that of the sector search pattern composite plot. That is, the "bias" is repeatable. Both of these composite plots show an error of 0.4 nm in a northerly direction and 0.2 nm in an easterly direction. As a consequence whenever the aircraft is on the same relative longitude but crossing latitudes, the error appears as an along track error. But when crossing longitudes along a fixed latitude the error shows as a cross track error.

Referring once again to Figure 5.8, it is informative to compare this plot to the data presented in Figure 5.9. That is, Figure 5.9 shows two Expanding Square patterns flown during the SAR test without utilizing the Loran-C navigator. On the Loran-C composite, the required 2.0 nm track spacing is accurately maintained throughout the entire pattern for five flights. In contrast, the conventional composite presented on Figure 5.9 shows large deviations from desired track, which exceed 1.0 nm in some portions.

To summarize, the overall flight test results of the Expanding Square pattern tests show that the Loran-C navigator was a considerable aid to the SAR crew in the execution of these types of patterns. Not only did the Loran-C navigator provide the pilot the capability to fly a nearly perfect pattern, but in so doing the pilot workload was held to a minimum. Therefore, the flight crew could concentrate on the primary objective of the SAR mission, which is to look for the missing target.

Immediately following the end of the sixth and last leg of the Expanding Square Pattern the return enroute segment to the Cape May base was begun. Figure 5.10 shows a composite of the aircraft actual cross track while on this segment, which is approximately 23.0 nm. In all cases the aircraft converged accurately to the desired Cape May waypoint. A minor discrepancy noted on this segment occurred when the pilot forgot to deselect the offset used in the execution of the Expanding Square pattern. This occurred twice, but in both of these cases

Figure 5.10 Loran-C SAR Operation Tests
Return Enroute Segment (22.5 nm) after completion of
SAR mission. Actual Cross Track Composite



the crew was able to detect the error and corrected it without major deviations from the desired track. The enroute segment was executed by selecting a leg change on the Loran-C navigator from the present position (0) to Cape May waypoint (9). This is the type of route segment typical of returning to a land based hospital subsequent to a successful rescue.

5.3 SURVEILLANCE ACCURACY ANALYSIS

This section presents the results of the accuracy and repeatability testing performed as substantiation of the Loran-C navigator's applicability to the Coast Guard Surveillance mission. As previously discussed in Section 4.3.2, these tests consisted of evaluating the feasibility of the Loran-C navigator in verifying the location of various types of targets. The tests consisted of performing a stabilized hover of 2 minutes duration at each of the designated targets while the Loran-C navigator indicated present position (latitude and longitude) was recorded. Due to safety considerations, the aircraft could not be positioned directly over the target. But in all cases, it was visually estimated that the aircraft was within 60 feet laterally in the same direction and 70 feet vertically of the desired target at the time of the data readings. The data taken over these locations was combined into Mean Position Error (F) and Circular Error Probability (CEP) statistics.

Three types of targets were included during the surveillance and helicopter hover mission -- three moored buoys at 16, 52 and 90 foot depths, a lighthouse approximately in the center of the Delaware Bay and a fixed landmark. The surveillance tests were flown by updating the Loran-C navigator prior to each flight at the Cape May helipad.

The results of the Surveillance tests indicate that the Loran-C navigator is an accurate operational aid in performing surveillance and enforcement type mission. The Loran-C navigator provides the pilot the capability to determine and define the target position using the helicopter present position at any time in terms of latitude/longitude or time differences. Consequently, when the desired location of a given target is required, the pilot only has to hover near the designated target to know its position accurately. Test results using the data recorded indicate the Loran-C navigator system tested performed accurately and repeatably in definition of the present position when flown over a designated target.

Table 5.4a presents a quantification of the Loran-C surveillance accuracy test results. This table presents the Mean Position Error, F, and CEP, both in feet, for each of the targets indicated. In addition, Table 5.4a summarizes the results of all the buoy data combined as well as all targets combined. An analysis of these data reveals that the Mean Position Error of the targets ranges from a minimum of 245.9 feet (SIE VORTAC, Inland) to a maximum of 1304.2 feet (0.21 nm) at the Five Fathom Buoy. The data aggregation of all the targets indicates a Mean Position Error of 734.8 feet (0.12 nm). The magnitude of these errors falls well within the specified tolerances (0.250 nm) of the Loran-C navigator. One of the peculiarities of the Loran-C navigator, observed and discussed thoroughly in previous sections, is the capability to repeat position data accurately. This is documented in Table 5.4a by examining the Circular Error Probability (CEP) computed for each of the targets. These CEP values range from a minimum of 86.1 feet to a maximum of 129.6 feet.

Table 5.4a Loran-C Surveillance Accuracy Test Mean Position Error and Circular Error Probability (CEP) of all Targets

Target Type	Mean Position Error (feet) F	CEP (feet)	Distance IP Offshore (nm)	Data Points	Anchor Chain Length	Approx. Depth
Sea Isle Vortac (Inland)	245.9	86.1±3%	—	20	—	—
Buoy No. 8 (Atlantic Ocean)	575.4	129.6±3%	2	18	180 ft	52 ft
Deadman's Shoul Buoy (Delaware Bay)	815.6	90.4±3%	3	19	48 ft	16 ft
Brandywine Lighthouse (Delaware Bay)	957.0	113.8±3%	7	20	—	—
Five Fathom Buoy (Atlantic Ocean)	1304.2	122.8±3%	16	19	540 ft	90 ft
All Buoys (Combined)	896.0	295.9±3%	—	56	—	—
All Targets (Combined)	734.8	377.0±3%	—	96	—	—

Interpretation of the results shown on Table 5.4a requires some explanation. Basically there are two types of numbers shown. First, the mean and CEP errors for individual locations whether the locations are buoys, lighthouses or VORTACS. Second, the mean and CEP aggregate statistics which represent the bounds of the errors to be expected for the entire population of buoys or the entire population of targets.

The way these two sets of numbers should be used is as follows. Examining the buoy data, it can be seen that the average CEP is 114.3 ft±3% with a mean of 896.0 ft. This implies that for any mission to locate a buoy, given the buoy placement position in latitude and longitude, the Loran-C navigator will:

- 1) Provide guidance to the buoy within an 896.0 ft mean position error in L/λ
- 2) Once the buoy is located, the new buoy position can be determined within a CEP of 114.3 ft±3% by hovering over the buoy and recording Loran-C indicated L/λ position

In addition, if it is desired to know the accuracy with which the Loran-C navigator can locate an entire group of buoys in a given channel or for entire set of inlets, then the statistically aggregated CEP of 295.9 ft±3% should be utilized. The mean error remains the same, 896.0 ft.

Figure 5.11 presents the surveillance data in another format. This figure shows the CEP plotted against the number of targets. Since one fixed location over land (SIE VORTAC) and one fixed location over water (Brandywine Lighthouse) were surveyed, these two points were plotted at "1". Similarly, three buoys were surveyed and resulted in a CEP of 295.9 ft. Finally, all five targets are aggregated and plotted at 377 ft. The trend of this curve is clear and as expected. That is, as the number of targets increases, the CEP approaches an asymptotic or limiting value. The best approximation to this limit obtained from the Loran-C flight testing was the 377 ft CEP.

A final comment regarding the numbers in Table 5.4a is that when the CEP's for aggregated data (all buoys or all targets) are examined it can be seen that the large variation in mean position error is transformed into an increased CEP. This was also shown to be the case when aggregating route segment statistics into overall enroute statistics in Table 5.3.

To summarize, if a known charted location is to be checked using the Loran-C then the CEP of the data taken will be accurate within $\pm 114.3 \text{ ft} \pm 3\%$. However, if a family of objects are to be located the achievable CEP should be on the order of $377.0 \text{ ft} \pm 3\%$.

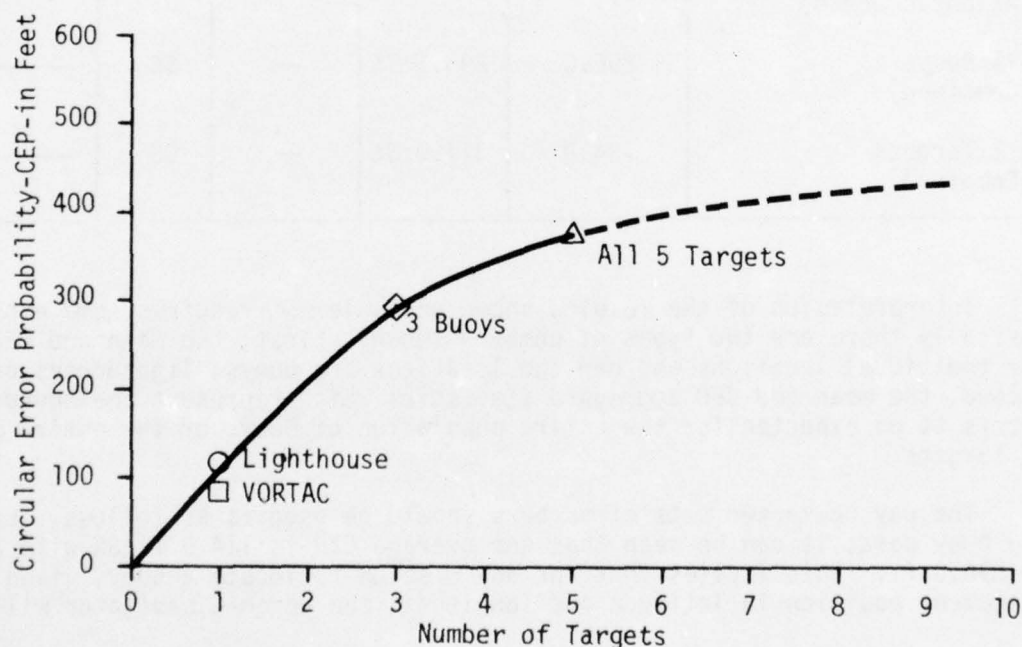


Figure 5.11 CEP Variation with Number of Targets

It should be noted at this time that only one data flight for surveillance purposes was flown per pilot compared to the three originally planned. This was due to one aborted mission and subsequent flight scheduling conflicts. Consequently, the surveillance data samples on each target were limited to approximately 20 readings. However, considering the accuracy and repeatability noted, the results and conclusions of the surveillance tests will not be impaired by the reduced data sample.

One aspect of the surveillance tests requiring documentation concerns the possible contribution of errors from known sources. One of these was the difficulty in defining the precise Cape May helipad coordinates (latitude/longitude) from which the Loran-C navigator could be updated prior to each flight during the surveillance testing. It is estimated that the referenced update used (Cape May helipad: $038^{\circ} 56.63' N$, $074^{\circ} 52.95' W$) was accurate within ± 200 feet. A second factor which contributes additional error is the buoy setting accuracy (placement of the anchor). A third factor contributing buoy position errors is the fact that buoys are on moorings which allow considerable movement around the anchor depending on chain length, wind and current. This was the reason for indicating anchor chain length in Table 5.4a. A fourth error is the definition of the actual target location. Except for the Sea Isle Vortac with a location which was geographically defined, all other locations were derived from topographical maps with a resolution of one inch to one nautical mile in latitude. Consequently, an error of ± 75 feet in defining the actual target coordinates would not be too large to expect, discounting the accuracy of the markings on the map itself. A final accuracy consideration was the fact that the aircraft was not hovered directly over the target. As can be seen, there is a small accuracy problem, usually negligible on other test work. However, because of the extreme accuracy required of the results of the surveillance tests where the over-all accuracy of all targets was 734.8 feet (Mean Position Error), these error contributions could be significant.

Figure 5.12 shows a pictorial presentation of the Mean Position Error and Circular Error Probability (CEP) of the surveillance data presented in Table 5.3. This presentation allows the assessment of the relative direction of the Mean Position Error with respect to the target's actual position. The pictorial presentation consists of a total of 7 plots, Figure 5.12(a) through (g). An inspection of these plots immediately reveals that in all cases, the magnitude of the Mean Position Error is largely attributable to an error in the latitude direction. In fact, the error in latitude is often nearly twice that of longitude. A suspected reason for this may be the inaccuracy inherent in the information from which the tested target locations were defined.

The fact that the Sea Isle Vortac (Figure 5.12(c) had negligible longitudinal error and the smallest latitude error, 237 feet) may be accounted for by the accuracy of its location, which was determined from geographical (surveyed) references, and which was not dependent on anchor setting, chain length or wind. In contrast, the location of the remaining targets were defined using markings on the NOS Loran-C charts. The south latitude direction of the 237 feet latitude position error of the Sea Isle Vortac is probably a result of the combined effects of a possible maximum error of 200 feet in the Cape May helipad location and the inaccuracy of visual approximation to hovering within 60 feet of the desired target. The surveillance data obtained during these tests indicated that the Loran-C navigator approaches the accuracy involved in defining the physical location to be flown.

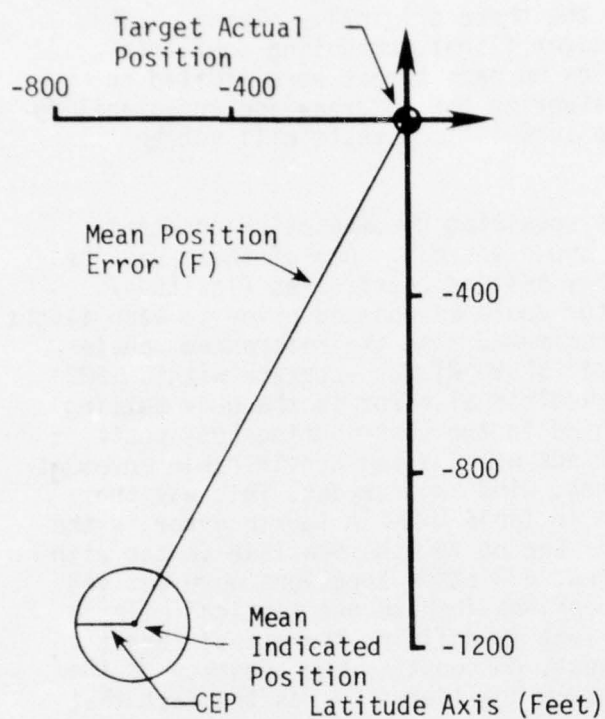


Figure 5.12(a)

Five Fathom Buoy (Offshore)
 $F = 1304.2$ feet
 $CEP = 122.8$ feet $\pm 3\%$

Figure 5.12(b)
 Brandywine Lighthouse (Inland)
 $F = 957.0$ feet
 $CEP = 113.8$ feet $\pm 3\%$

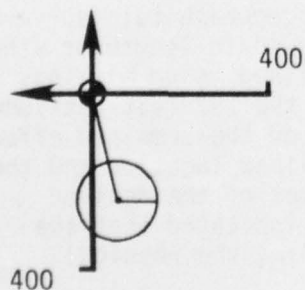
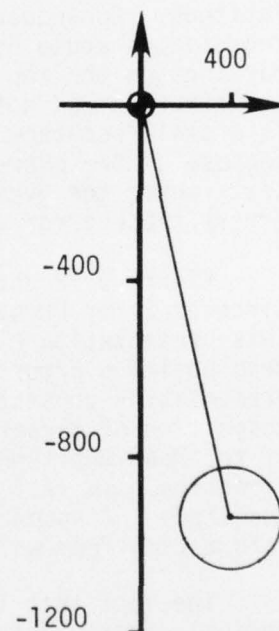


Figure 5.12(c)
 Sea Isle Vortac (Inland)
 $F = 245.98$ feet
 $CEP = 86.15$ feet $\pm 3\%$

Figure 5.12 Loran-C Surveillance Accuracy, Mean Position Error and Circular Error Probability (CEP) of Targets

Figure 5.12(d)
 Deadman's Shoal Buoy (Offshore)
 $F = 815.6$ feet
 $CEP = 90.4$ feet $\pm 3\%$

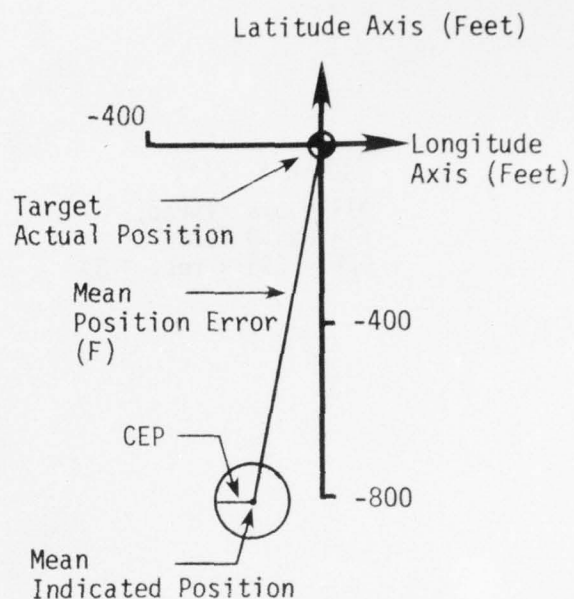


Figure 5.12(e)
 Buoy No. 8 (Offshore)
 $F = 575.4$ feet
 $CEP = 129.6$ feet $\pm 3\%$

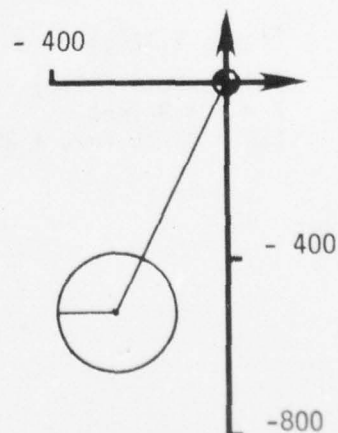


Figure 5.12 (continued)

Loran-C Surveillance Accuracy, Mean Position Error and Circular Error Probability (CEP) of Targets

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SYSTEMS CONTROL INC P/LO ALTO CALIF
AN OPERATIONAL FLIGHT TEST EVALUATION OF A LORAN-C NAVIGATOR.(U)
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Figure 5.12(f)
 All Buoys (Three)
 $F = 896.0$ feet
 $CEP = 295.9$ feet $\pm 3\%$

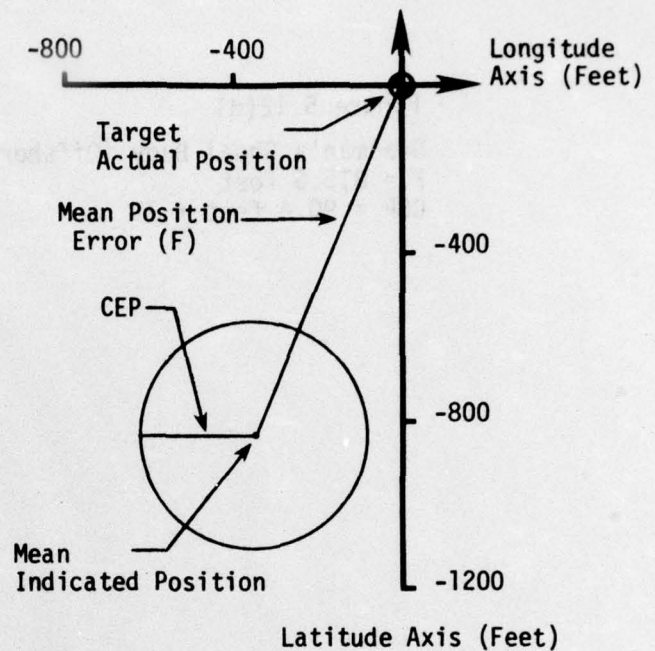


Figure 5.12(g)
 All Targets (Five)
 $F = 734.8$ feet
 $CEP = 377.0$ feet $\pm 3\%$

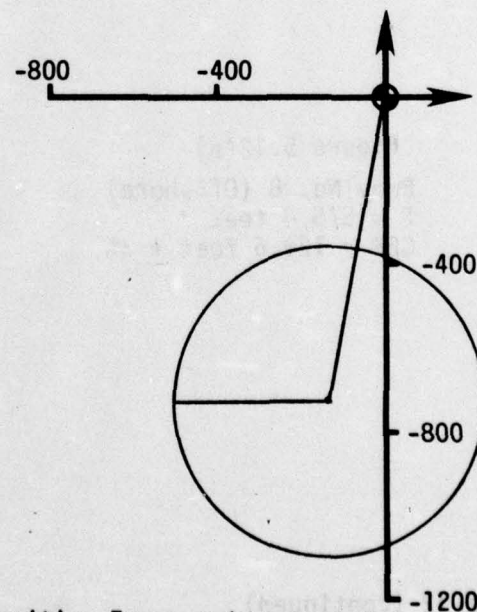


Figure 5.12 (continued)

Loran-C Surveillance Accuracy, Mean Position Error and
 Circular Error Probability (CEP) of Targets

Another interesting comment about these plots is the consistency of the Mean Indicated Position of all the buoys in a direction slightly southwest of the actual targets. In contrast, both of the fixed targets, Sea Isle Vortac and the Brandywine Lighthouse, show a Mean Indicated Position in a direction due southeast of the respective actual locations.

Figure 5.13 is presented to show the expected accuracy of the Loran-C navigator without making use of the position update capability. Throughout the Loran-C flight test program, and prior to each data flight, the aircraft was positioned over the Cape May helipad and its indicated Loran-C present

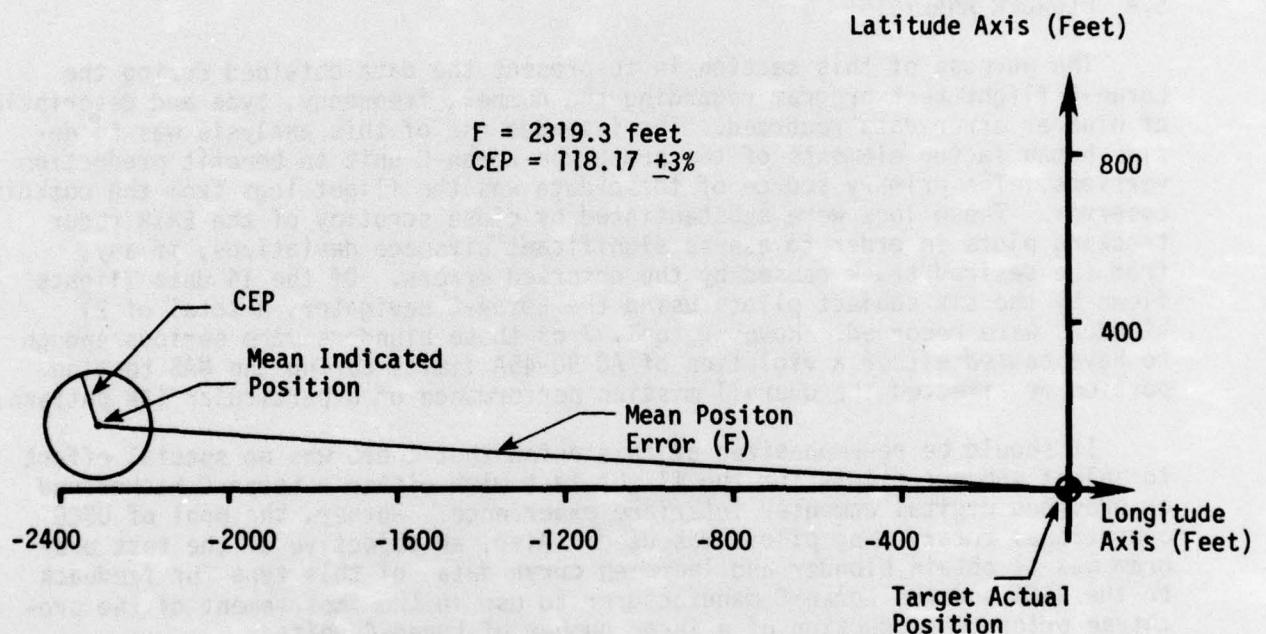


Figure 5.13 Loran-C Surveillance Accuracy, Mean Position Error and Circular Error Probability (CEP) of Cape May (helipad) with No Correction (update)

position recorded. A total of 23 data readings were recorded. Figure 5.13 shows a significantly large Mean Position Error (2319 feet, 04. nm) which appears to be solely a function of longitudinal direction. The repeatability of the data is indicated by the reduced magnitude of the CEP (118.17 feet). These results then compared to the data from Table 5.3 and Figure 5.11 definitely indicate the quantitative improvement in accuracy whenever the Loran-C functional update capabilities are used. Consequently, for the Surveillance and Enforcement type missions, where the determination of position accuracy is considered essential, the Loran-C navigator should be updated prior to each flight for maximum accuracy.

Reviewing the over-all results of the surveillance tests it is concluded that the Loran-C navigator in its present configuration, and whenever its present indicated position had been previously updated, provides the pilot the ability to accurately define the location of any given target.

5.4 BLUNDER ANALYSIS

The purpose of this section is to present the data obtained during the Loran-C flight test program regarding the number, frequency, type and description of blunder error data recorded. The intended use of this analysis was to define human factor elements of the prototype Loran-C unit to benefit production versions. The primary source of these data was the flight logs from the cockpit observer. These logs were substantiated by close scrutiny of the EAIR radar tracking plots in order to assess significant airspace deviations, if any, from the desired track caused by the observed errors. Of the 14 data flights flown by the six subject pilots using the Loran-C navigator, a total of 21 blunders were recorded. However, only 7 of these blunders were serious enough to have caused either a violation of AC 90-45A limits during the NAS testing portion or affected the overall mission performance of a particular SAR pattern.

It should be re-emphasized at this point that there was no special effort to select subject pilots for the flight test with either a Loran-C background or previous digital computer interface experience. Rather, the pool of USCG operational rotary wing pilots was used. Also, an objective of the test program was to obtain blunder and learning curve data of this type for feedback to the USCG and the Loran-C manufacturer to use in the improvement of the prototype prior to production of a large number of Loran-C units.

At the end of this section a detailed discussion of each blunder error recorded is presented for documentation purposes as well as for reference throughout this text. The blunder error discussion is itemized one (1) through twenty-one (21). Each blunder discussion presented has the same format as follows: The type of error, test type (SAR or NAS), part of the flight where the error took place, test number and a yes/no assessment of whether or not the SAR mission was affected by the observed error or the AC 90-45A limits were violated (NAS).

Before analyzing the recorded blunder data, Tables 5.5 through 5.6 are presented to summarize the types and frequency of the blunder errors recorded. Table 5.5 classifies the types of errors by category, by the number of errors for each mission and by mission type. Analysis of these data indicates that of the 21 total errors recorded, 18 were a result of pilot-initiated errors and the remaining 3 were due to an equipment (Loran-C navigator) malfunction.

Table 5.5 Blunder Error Count By Type and Number for Each Mission

TYPES OF ERRORS	NUMBER OF TIMES	MISSION	
		SAR	NAS
<u>Pilot-Initiated Blunders</u>			
Wrong Leg Selected	5	4	1
Overshoot	4	2	2
Wrong Offset Input	3	2	1
Forgot to Deselect Offsets	2	2	
Wrong Waypoint Input	1	1	
Steering Horizontal	1	1	
Turned to Wrong Heading	1	1	
In-Flight Re-Acquiring of Loran-C	1		1
SUBTOTALS	18	13	5
<u>Equipment-Initiated Blunders</u>			
Rejected Leg Change	1	1	
Rejected Offset Input	1	1	
Receiver in Energy Track	1		1
SUBTOTALS	3	2	1
TOTALS	21	15	6

Table 5.5a Blunder Error Count by Pilot For SAR Flights

SAR FLIGHT PHASE	SUBJECT PILOTS						TOTALS
	A	B	C	D	E	F	
ENR	1	0	2	1	1	*	5
CL	1	2	0	0	2	*	5
SS	0	0	1	1	*	*	2
Square	1	0	0	0	0	*	1
TOTALS	3	2	3	2	3	—	13

*Was not flown

Table 5.6 Blunder Error Count By Pilot For NAS Flights

NAS FLIGHT PHASE	SUBJECT PILOTS						TOTALS
	A	B	C	D	E	F	
ENR	0	0	0	0	0	0	0
SID	0	0	0	0	0	1	1
STAR	0	0	0	1	1	1	3
Approach	0	0	0	0	0	1	1
TOTALS	0	0	0	1	1	3	5

There were four types of errors that were repeated at least twice. The most prevalent was the wrong selection of leg-change (5 times); followed by overshoot of waypoints (4 times); the wrong input of offsets (3 times); and finally, forgetting to deselect a previously entered offset (2 times); These four different categories of errors account for nearly 70% of the total errors recorded (all pilot-initiated) during the Loran-C flight test program. Of all of the pilot-initiated errors (18), 13 of these occurred during the SAR testing (5 data flights) and 5 during the NAS testing portion (7 flights).

A detailed analysis of the 18 blunders (pilot-initiated) reveals that only 5 errors (SAR (2); NAS (3)) actually were serious enough to affect the mission (SAR) or airspace required (NAS). The 2 errors recorded during the SAR tests were almost identical and were concerned with the execution of the first cross-leg of the sector search pattern. (See blunder Items 2 and 3). The other 3 errors (NAS) were due to turn overshoot, wrong offset input and in-flight re-acquiring of Loran-C, respectively. The latter two errors were considered most serious. On the first one, (blunder Item 12) the crew selected a 3.0 nm left-offset instead of a 3.0 nm right-offset. The cockpit observer had to call the error to the pilot's attention in order to salvage valid flight test results. This type of error could have resulted in a traffic conflict if under real ATC operating procedures in a busy terminal area. The second error (blunder Item 18) was produced as a result of lack of training procedures in re-acquiring use of Loran-C following a five minute period that the Loran-C master station was off the air. As a result, protected airspace limits were violated and the pilot had no option but to cancel the RNAV approach clearance and revert to VOR/DME (conventional) navigation mode.

Additional analysis of Table 5.5 indicates that out of 3 recorded equipment-initiated errors, two (2) resulted in actual deviation of the intended flight profile. One of these occurred during the SAR tests (sector search blunder Item 9) where the crew could not make the Loran-C navigator accept a required leg change. This occurred while in the Time/Brg display select mode required to complete the first cross-leg of the sector search pattern. The other error occurred during a NAS flight (blunder Item 21) causing the aircraft to exceed AC 90-45A limits. This error, unknown to the flight crew, was caused by the Loran-C receiver operating in energy track (dead-reckoning mode) as a result of temporary loss of signal by the receiver. This particular type of discrepancy may be expected to occur in actual Loran-C navigator operations.

Tables 5.5a and 5.6 each present a distribution of all the blunder errors recorded, by subject pilot for SAR and NAS flights, respectively. A most interesting aspect upon comparing the blunder errors on Tables 5.5a and 5.6, is the drastic reduction of blunder errors recorded during the NAS test phase (5 errors in 6 flights) versus the SAR testing portion (13 errors in 5 flights). The primary reason for this is that in all cases the SAR flights preceded the NAS flights, and consequently the pilots had acquired considerable experience and training in operating the Loran-C navigator. The SAR flights provided the crew the opportunity to exercise nearly all the functions provided by the Loran-C navigator and in less time due to the shorter legs flown. As a result, the NAS blunders were significantly reduced.

The definition of a subject pilot learning curve applicable to the utilization of the Loran-C navigator is not possible because of the low samples of flights for each subject (generally only 2 flights). However, a visual

inspection of the total blunder error data per subject pilot, as shown in Table 5.6, indicates that on the average all pilots had the same rate of errors (2.6) in their initial data flight of the Loran-C flight test program. These results, further substantiated by the drastic reduction of blunder errors committed by the subject pilots on their second flight (average of 1 error per flight), illustrates a satisfactory learning process.

Following is the detailed discussion of each of the blunder errors which occurred on the data flights of the Loran-C flight test program.

- | | |
|----------------------------|---------------------|
| 1. TYPE OF ERROR: | Wrong Leg Selected |
| TEST: | SAR |
| WHERE: | Enroute, Test No. 3 |
| MISSION AFFECTED: | No |
| EXCEEDED AC 90-45A LIMITS: | N/A |

Description of Error: (Reference Figure 5.8)

After completion of the sector search pattern, leg change from present position (0) to a designated waypoint on sector search (8) was selected instead of leg change from present position (0) to CSP of an expanding square (1). Initial CDI indications were to fly-right, which the pilot immediately followed, but the copilot caught the error very quickly, mainly because he was expecting a CDI fly-left indication. By the time the aircraft was turned around it was approximately 1.4 nm right of desired track (end of sector search to CSP of expanding square). The proper leg change selection was made almost at the conclusion of the turn.

- | | |
|----------------------------|---------------------------|
| 2. TYPE OF ERROR: | Wrong Leg Selected |
| TEST: | SAR |
| WHERE: | Sector Search, Test No. 7 |
| MISSION AFFECTED: | Yes |
| EXCEEDED AC 90-45A LIMITS: | N/A |

Description of Error: (Reference Figure 5.7(c))

First cross-leg of sector search was executed on a bearing of 317° to waypoint (2nd waypoint of initial leg) instead of on a bearing of 300° but to waypoint 7 (datum) as a pre-established flight test procedure. Pilot noticed error when about 1.0 nm to datum. Re-selected leg change 0 to 7 at an airplane heading of 300°. Consequently, no adequate coverage on the desired sector search pattern resulted from the first cross-leg flown on this specific flight.

- | | |
|----------------------------|---------------------------|
| 3. TYPE OF ERROR: | Wrong Leg Selected |
| TEST: | SAR |
| WHERE: | Sector Search, Test No. 8 |
| MISSION AFFECTED: | Yes |
| EXCEEDED AC 90-45A LIMITS: | N/A |

Description of Error: (Reference Figure 5.7(d))

Error very similar to the one just described (blunder Item 2, Test No. 7). The same improper procedures were utilized on both of these flights in the execution of the first cross-leg of the sector search pattern. Both of these

flights were flown utilizing the same crew (subjects C and D) but alternating pilot/copilot on each one of them. Incidentally, this crew was told of this particular error committed during the post-flight debriefing of Test No. 7.

4. TYPE OF ERROR:	Wrong Leg Selected
TEST:	SAR
WHERE:	Enroute, Test No. 13
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error

Crew selected the initial enroute segment (leg change) of the flight from Cape May (W/P 9) to the CSP of the expanding square (W/P 1) instead of to the CSP of the creeping line (W/P 4) pattern. This particular error was not caught by the test crew, rather, the observer had to mention it in order to acquire the desired data. Time elapsed before the observer told the crew of the error was approximately 3 minutes. The reason that the CSP of the expanding square was selected was that it was listed as the No. 1 waypoint on the flight card vs the CSP of the creeping line where it is designated as the No. 4 waypoint. Before the observer told the crew of the error, he asked where they were proceeding to. The answer was "To execute the creeping line pattern". It is conceivable that an error of this type could have a significant adverse effect under actual operational conditions in a real SAR environment. Therefore, definite operational procedures concerning the proper designation of waypoints in the proper order in which they are to be entered and the recall order by the crew should be developed and discussed thoroughly in the Loran-C navigator flight manual or user handbook and/or during pre-flight SAR operating procedures.

5. TYPE OF ERROR:	Wrong Leg Selected
TEST:	NAS
WHERE:	STAR, Test No. 14
MISSION AFFECTED:	N/A
EXCEEDED AC 90-45A LIMITS:	No

Description of Error (Reference Figure 5.5)

The crew had been given an impromptu route change clearance by the observer at 3.0 nm to GOLF in the V-G segment, as follows:

"Maintain Present Heading Past GOLF Waypoint to Intercept,
a 3.0 nm Left Offset on Base Leg".

At the time of the clearance the Loran-C navigator was being operated in the AUTO mode (automatic leg change at waypoint passage). The aircraft arrived at GOLF waypoint on a previously selected leg, VICTOR (1) to GOLF (2) and the navigator automatically changed to a new leg, GOLF (2) to HOTEL (3), because the pilot had left the Loran-C navigator in the AUTO mode. What was expected of the crew was to re-select the MANUAL mode, so that the Loran-C navigator would still retain the leg VICTOR (1) to GOLF (2) and could provide positive navigation guidance. As a result of the automatic leg change, dead-reckoning navigation had to be used to intercept the desired 3.0 nm left offset track. This was executed by selecting the 3.0 nm left offset after the automatic leg change (2-3) took place. The pilot kept the same heading until the CDI indications (± 0.5 nm full scale) began to indicate the proximity of the desired track (offset), at which time a turn was initiated.

6. TYPE OF ERROR:	Overshoot
TEST:	SAR
WHERE:	Creeping Line, Test No. 3
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error: (Reference Figure 5.6(a))

The CSP (Waypoint No. 4) of the creeping line pattern was overshoot by approximately 1.0 nm. The overshoot caused the aircraft to be 1.2 nm right of desired track during the commencement of the initial creeping line leg. The Loran-C navigator was operated in the MANUAL mode during this period. Contributing factors to the overshoot may have been a combination of the following: First, the crew was distracted from their primary objective which was to get to the desired CSP by reviewing different methods of off-set entry. In addition, the pilot's instrument panel does not have a readout of Distance-To-Waypoint (DTW). The only two ways that the crew could sense waypoint passage was by monitoring the digital readout display of DTW as provided by the Loran-C navigator (only if the particular selector mode has been pre-selected) or to monitor the TO/FROM flag switchover of a course indicator located in the lower center left of the pilot's instrument panel.

7. TYPE OF ERROR:	Overshoot
TEST:	SAR
WHERE:	Creeping Line, Test No. 6
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error: (Reference Figure 5.6(a))

The CSP (Waypoint No. 4) of the creeping line pattern was overshoot by approximately 1.0 nm. The reason for the overshoot was that the copilot entered waypoint data when the aircraft was known to be relatively close to the CSP waypoint. The copilot was doing waypoint entry for waypoints not immediately required for navigation. By the time the copilot finished these waypoint entries, and the display selector was switched to DTW/CTD mode, the aircraft was on the desired track but approximately 1.0 nm past the waypoint. The pilot then turned right (270°) to minimize the resultant error and therefore increased the SAR pattern coverage/effectiveness.

8. TYPE OF ERROR:	Overshoot
TEST:	NAS
WHERE:	Approach, Test No. 19
MISSION AFFECTED:	N/A
EXCEEDED AC 90-45A LIMITS	Yes

Description of Error: (Reference Figure 5.4(c))

The Initial Approach Fix (IAF waypoint HOTEL) of the final approach segment to NAFEC R/W 04 was overshoot by 0.8 nm. The Loran-C navigator was operated in the leg-change AUTO mode. Upon crossing the HOTEL waypoint, the automatic leg change occurred (HOTEL (3)) to INDIA (4) but the crew did not notice it until 0.8 nm past HOTEL waypoint. The crew became aware of the

overshoot because of the increasing CDI fly-left indications while maintaining the same track heading of the previous selected leg (GOLF-HOTEL). Once the error was discovered, the pilot initiated a 90° left turn and began correcting the overshoot using the CDI. The violation of AC 90-45A accuracy limits was marginal, 0.8 nm instead of 0.6 nm limits, but significant.

9. TYPE OF ERROR:	Overshoot
TEST:	NAS
WHERE:	SID, Test No. 19
MISSION AFFECTED:	N/A
EXCEEDED AC 90-45A LIMITS:	No.

Description of Error: (Reference Figure 5.2)

The SIERRA waypoint of the ATLANTIC CITY ONE RNAV DEPARTURE (SID) was overshoot by approximately 1.5 nm. The copilot began monitoring of the Loran-C navigator DTW display to waypoint SIERRA at about 1.5 nm prior to waypoint intersection so that he could signal the pilot to begin the desired right turn towards the next waypoint (VICTOR). The copilot did not notice SIERRA waypoint passage, until approximately 1.3 nm "FROM" it. He became aware of error when he first realized that DTW display numbers were increasing rather than decreasing. Error correction immediately followed. The Loran-C navigator was operated at this time in the MANUAL mode, primarily because of the requirement to do a leg change at SIERRA (8) to VICTOR (1) where if the automatic mode had been selected it would provide undesired leg change SIERRA (8) to CAPE MAY (9) because of the established numerical sequence of stored waypoints.

10. TYPE OF ERROR:	Wrong Offset Input
TEST:	SAR
WHERE:	Creeping Line, Test No. 6
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error: (Reference Figure 5.6(a))

Forgot to set the L/L-TD switch to TD, while entering a 4.0 nm right offset (third leg of creeping line pattern). The Loran-C navigator operator's manual (Reference 6) explicitly defines that parallel track input procedures requires the selection of the L/L-TD switch to the TD position. The published parallel track input procedure is as follows: While in OPERATE mode set display to DSRTK/TKE mode and set L/L-TD switch to TD, depress CLR and GRI keys, then proceed to enter desired offsets in keyboard and finally depress INSERT. It is evident that the numerous required steps to select an offset in the present Loran-C navigator configuration resulted in the omission of the TD step. Although the 4.0 nm right offset was improperly entered, it was accepted by the Loran-C navigator. The WARN light indicator remained off during the offset entry period as well as during the actual use of it by the crew. The observer caught the error and then requested the crew repeat the exact procedures used for the 4.0 nm right offset for next offsets (6L, 9R and 10L). The results were as before. The Loran-C system was capable of accepting offset entry without having to select the L/L-TD switch to the TD position. No navigation error effects were noticed during the execution of the offsets or thereafter by utilizing this procedure used in the selection of the 4.0 nm right offset.

11. TYPE OF ERROR:	Wrong Offset Input
TEST:	SAR
WHERE:	Creeping Line, Test No. 13
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error: (Reference Figure 5.6(a))

Entered a 2.0 nm right offset instead of a 2.0 nm left offset, as required to perform second leg of creeping line pattern. The aircraft was being flown (dead reckoning) in the transition segment between the end of the first leg and the beginning of the second leg of the creeping line pattern. The crew became aware of the error because as the aircraft was being flown in the direction of the second leg, the CDI indications showed a pegged (0.5 nm) needle (fly-right) instead of the expected fly-left and secondly, an increasing value (nm) on the DTW readout, instead of decreasing to the 5.0 nm (DTW) which would signify the interception of the second leg (2.0 nm left offset). The copilot rechecked the offset entered and verified the error, which was immediately corrected, but not before the aircraft had overshoot the inbound turn by 0.5 nm.

12. TYPE OF ERROR:	Wrong Offset Input
TEST:	NAS
WHERE:	STAR, Test No. 19
MISSION AFFECTED:	N/A
EXCEEDED AC 90-45A LIMITS:	Yes

Description of Error: (Reference Figure 5.5)

Entered a 3.0 nm left offset instead of the 3.0 nm right offset requested by the impromptu route change clearance. The crew did not suspect the error or even question their present navigation status during the period (2 minutes) in which they actually followed a constant fly-left CDI indication (needle pegged, 0.5 nm) at a course intercept angle of 45°. The observer had to tell crew of the error, which was finally corrected at a maximum deviation from desired offset track of 2.0 nm. It is evident that an error of this type could have caused a traffic conflict under real operating conditions in a busy terminal area.

13. TYPE OF ERROR:	Forgot to Deselect Offset
TEST:	SAR
WHERE:	Enroute, Test No. 7
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error: (Reference Figure 5.10)

The return enroute leg from the end of the expanding square pattern to CAPE MAY waypoint (base) was input while still using the 2.0 nm right offset used in the execution of the expanding square pattern which had not been deselected. The copilot caught the error 30 seconds after the Direct-To enroute leg change entry and corrected it. No major discrepancies were noted.

14. TYPE OF ERROR:	Forgot to Deselect Offset
TEST:	SAR
WHERE:	Enroute, Test No. 8
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error: (Reference Figure 5.10)

Same as described on blunder Item No. 13, except the error was detected by pilot. The pilot desired to maintain the same aircraft heading as that of the last leg of the expanding square pattern. The copilot was slow in removing offset. As a consequence of lateness (1 minute) in removing offset from the time it was discovered, the actual aircraft position had deviated approximately 1.0 nm to the right of desired track (enroute leg) once desired Loran-C navigation was resumed.

15. TYPE OF ERROR:	Wrong Waypoint Input
TEST:	SAR
WHERE:	Enroute, Test No. 7
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error:

During pre-flight waypoint entry, the CSP waypoint (No. 1 of the expanding square pattern) was input incorrectly. This error was characterized by transposing two numbers of the longitude of the particular waypoint. Instead of selecting longitude 074° 25.28', it was selected 074° 52.28'. The copilot performed all waypoint entries and operated the overall functions of the Loran-C navigator. The copilot usually checked all of his waypoint entries, but still did not discover the error. However, after selection of leg change (end of sector search to the CSP, Waypoint No. 1 of the expanding square), the crew became aware of an error because of a DTW readout of 24.0 nm instead of the expected 9.0 nm, as specified in the pre-flight briefing. The copilot cross-checked the desired waypoint entry versus the ones previously entered in the Loran-C navigator and upon finding the error, corrected it. Time elapsed during the troubleshooting error/correcting procedure was 30 seconds. No deviations from desired cross track were noted, mainly because the pilot turned the aircraft to a northbound heading (360°) which he knew from the pre-flight briefing was the desired heading.

16. TYPE OF ERROR:	Steering Horizontal
TEST:	SAR
WHERE:	Creeping Line, Test No. 13
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error: (Reference Figure 5.6(a))

After turning at the desired CSP (Waypoint No. 4) of the creeping line pattern, the pilot did not follow the CDI fly-left indications to intercept the desired track of the first leg of the search pattern. The maximum CDI fly-left indication was 0.8 nm (aircraft right of desired track) corresponding to an along track distance of 2.0 nm past the CSP and on the first leg of the creeping line pattern. After this short period (2.0 nm) of inaccurate aircraft steering, the pilot proceeded to intercept and then maintain the desired track as the CDI needle deflections indicated.

17. TYPE OF ERROR:	Turned to Wrong Heading
TEST:	SAR
WHERE:	Expanding Square, Test No. 3
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error: (Reference Figure 5.8)

The aircraft was flown to the desired CSP (Waypoint No. 1) of the expanding square pattern in the Loran-C navigator AUTO mode (automatic leg change at waypoint passage). However, the AUTO mode feature did not work, and while the copilot was manually selecting the desired leg change (W/P 1 to W/P 2), the pilot suddenly turned the aircraft to the left at the W/P 1 (CSP) crossover. The copilot told the pilot to maintain previous heading and that the turn to the left was not required until arrival at waypoint 2. The pilot turned the aircraft to the proper heading and resumed following normal navigation.

18. TYPE OF ERROR:	In-Flight Re-Acquiring of Loran-C
TEST:	NAS
WHERE:	STAR, Test No. 20
MISSION AFFECTED:	N/A
EXCEEDED AC 90-45A LIMITS:	Yes

Description of Error: (Reference Figure 5.3)

Following a five minute period that the Loran-C master station was off the air, the crew could not re-acquire Loran-C navigation. The crew failed (during their various troubleshooting attempts) to re-enter approximate present position (within 100 nm) as required for the in-flight re-initialization of the Loran-C navigator. The Loran-C master station went off the air in the initial segment of the NAFEC ONE RNAV SOUTH ARRIVAL (VICTOR to GOLF waypoints).

When the Loran-C master station went off the air, the Loran-C navigator WARN advisory indicator lighted continuously, and at the same time the CDI indicated a full flight-right indication which the pilot followed, thereby a total cross track deviation of 2.0 nm to the right of desired track occurred as shown on Figure 5.3. At this time the pilot abandoned chasing the CDI needle and initiated a 45° intercept (dead-reckoning) towards the route segment (V-G). The pilot maintained this heading for approximately 5 minutes at which time the crew decided to abort the Loran-C test and contacted ACY Approach Control to cancel the RNAV approach.

19. TYPE OF ERROR:	Equipment (Rejected Leg Change)
TEST:	SAR
WHERE:	Sector Search, Test No. 6
MISSION AFFECTED:	Yes
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error: (Reference Figure 5.7(b))

The crew could not make the Loran-C navigator accept a leg change from present position (0) to the sector search datum waypoint (7) at the completion of the first cross leg of the sector search pattern. The Loran-C navigator

display selector was, at this time, in the Time/Brg position since the crew was monitoring bearing changes for waypoint 7 in order to enter leg change (0 to 7) at the required bearing intercept. The copilot tried several times to enter the leg change 0 to 7 but each time was unsuccessful. Finally, the display selector mode switch was rotated back and forth several times and stopped at the CTD/DTW position. The leg change was then accepted by the Loran-C navigator.

While the copilot was troubleshooting the system anomaly, the pilot proceeded to turn the aircraft inbound towards the datum (Waypoint No. 7) using deadreckoning. Once the leg change entry was achieved, the pilot began to intercept the desired track heading by following normal Loran-C navigation. The copilot then selected the time/brg position on the display selector and the pilot began correcting aircraft heading in search of a bearing of 300° from the datum for the desired cross leg change. Once the 300° bearing was intercepted, the pilot began to turn the aircraft towards the datum at the same time the copilot selected the new leg change (0-7). Due to the proximity of the aircraft to the datum (0.3 nm) at the time of the last leg change it is possible that this may be the reason that the second cross leg is farther to the north instead of the desired northwest (300°).

20. TYPE OF ERROR:	Equipment (Rejected Offset Input)
TEST:	SAR
WHERE:	Creeping Line, Test No. 8
MISSION AFFECTED:	No
EXCEEDED AC 90-45A LIMITS:	N/A

Description of Error: (Reference Figure 5.6(a))

Three attempts were required by the crew for the Loran-C navigator to accept a 6.0 nm left offset input required for the execution of the fourth leg of the creeping line pattern. On the first attempt the Loran-C navigator removed the previously entered 4.0 nm right offset which was utilized for the creeping line pattern third leg. The Loran-C navigator DTW/CTD displays would show accurate navigation indications but referenced to the basic leg (initial) from which the offsets were to be referenced. The WARN advisory indicator light was off during this period. No direct impact to the overall performance of the SAR mission resulted mainly because the crew was able to detect the system anomaly and the pilot maintained aircraft heading. Nevertheless, a 1.0 nm overshoot of the fourth leg resulted before the crew could turn the aircraft to the desired track, once normal Loran-C navigation was resumed.

21. TYPE OF ERROR:	Equipment (Loran-C Receiver in Energy Track)
TEST:	NAS
WHERE:	STAR, Test No.
MISSION AFFECTED:	N/A
EXCEEDED AC 90-45A LIMITS:	Yes

Description of Error: (Reference Figure 5.3)

As a result of a temporary loss of signal by the Loran-C receiver (unknown to the flight crew) the receiver went into a dead-reckoning mode (energy track) for derivation of the pertinent navigation information. This particular discrepancy occurred while on the STAR portion (V-G) of this flight and caused the aircraft to exceed AC 90-45A limits. This discrepancy severely affected the ability of the Loran-C receiver to provide accurate navigation information in reference to the desired track. Maximum aircraft cross track deviation from desired track was 1.6 nm for an along track period of 10 nm (approximately 5 minutes).

5.5 PROTOTYPE LORAN-C NAVIGATOR EQUIPMENT PROBLEMS

This section summarizes operationally significant problems encountered during the performance of the Loran-C navigator flight test program. Equipment problems discussed include Loran-C hardware/software problems, display type and location problems, leg change or waypoint sequencing problems, input workload problems and Loran-C bias data.

Section 5.5.1 summarizes each of these problems from the viewpoint of what was wrong and why it was wrong. In addition, an example of the impact of each problem is provided.

Section 5.5.2 provides recommendations regarding what could be done to alleviate or reduce the occurrence of these problems.

5.5.1 Operational Deficiencies of the Loran-C Navigator System

1. Inadequate Waypoint Passage Indications

Problem Summary - The To/From flag driven by the Loran-C navigator was located on a display outside the primary scan pattern of the pilot.

Discussion

The test aircraft was instrumented with a Course Indicator display (ID-351) located in the bottom center of the front instrument panel. The course indicator display allowed the pilot to determine when a particular waypoint was reached by monitoring the TO/FROM flag. However, the course indicator was seldom used by the pilot to detect waypoint passage. Alternatively, the DTW digital display of the Loran-C navigator was used to determine the waypoint passage. The reason for this was the poor location of the course indicator which was not in the pilot's primary scan of the navigational flight instruments.

On a typical flight the pilot would concentrate on correcting the aircraft cross track deviation as shown on the Navigator Flight Director Indicator which did not include a TO/FROM flag. The copilot monitored (heads down) the Loran-C navigator distance to waypoint (DTW) display and called out pertinent readouts to the pilot. This procedure resulted in an increase in cockpit workload whenever the aircraft was approaching a waypoint. In addition, several overshoots of waypoints occurred in the NAS and SAR testing because either the copilot failed to notice waypoint passage or the pilot reacted late in turning the aircraft according to the copilot's call.

Impact

Overshoots of this type and magnitude were typically caused by lack of recognition of waypoint passage. In particular the turns performed during the creeping line and expanding square patterns exhibited undesirable overshooting tendencies. In the NAS environment these overshoots can casue ATC conflicts. In the SAR environment, the higher workload in the turn area detracts from the crews capability to locate the target.

2. Offset Track with Manual and Automatic Leg Change Selection

Problem Summary - The Loran-C navigator projects parallel offset course waypoints in two different ways depending on mode of operation selected (auto or manual).

Discussion

The execution of offsets during the Loran-C flight test program indicates that confusion may result from the interpretation of offset track intersection depending on the method of leg change selected (automatically or manually) by the pilot. If an offset is performed based on a manually selected leg change, the resultant offset track will be projected along the perpendicular projection of the referenced "TO" waypoint. If on the other hand, an offset is performed based on an automatically selected leg, then the resultant offset track will be projected along the bisector angle of the parent track and the following track. The major operational impact of having two different methods to define an offset track which results in a disagreement of offset track length is an increased blunder potential. This was evidenced during the execution of impromptu traffic route clearances (offsets and direct-to) during the NAS testing portion (see Figure 5.6). For instance, on the 3.0 nm right offset or base leg (G-H) to intercept final approach course (clearance), two times out of three resulted in the wrong execution. The reason for this was that in these two instances, the offset was established on a manually selected leg. Then when the aircraft was approximately 3.0 nm DTW, the pilot thought he was on the centerline of the final approach course and therefore proceeded direct-to HOTEL. What happened was that the pilot misunderstood the basic definition of the offset he just entered and considered the 4.0 nm DTW as the remainder of the offset track, which would have put the aircraft 3.0 nm right offset of the final approach course.

Impact

The two techniques for offsetting waypoints provides inconsistent maneuvering of the aircraft when the offset is cancelled. This is not acceptable from an air traffic control viewpoint since the goal of ATC is to reliably maneuver aircraft regardless of navigation system characteristics. In addition, these two different waypoint offset techniques add an extra task to the pilot's workload in flying offsets. As a consequence, blunder potential is increased.

3. Automatic Waypoint Sequencing (Leg Change)

Problem Summary - Waypoint sequencing cannot be satisfactorily performed using a fixed radius or diameter circle around the waypoint due to actual aircraft deviations from desired track.

Discussion

In the tested configuration the automatic waypoint sequencing was adjusted to take effect whenever the aircraft was within a 1600 foot circle of the referenced waypoint. Consequently, if the actual course deviation indicated by the CDI needle deflection was greater than 1600 feet (0.26 nm) at waypoint passage, (abeam the waypoint) the automatic waypoint sequencing would not take place. The pilot then had to manually select the next leg, determining waypoint passage and monitoring the TO/FROM flag change.

Another problem presented by the automatic waypoint sequencing was the elimination of the Missed Approach Waypoint (MAP) when the DTW was less than 0.26 nm, leaving the pilot without navigation to complete his final approach.

Impact

Unacceptable turn overshoots can be expected for both SAR and NAS missions with the current waypoint sequencing techniques. In addition, pilot disorientation was observed using this technique. Finally, the loss of guidance for the last 0.26 nm on final approach precludes executing a missed approach and could cause a hazardous situation.

4. Loran-C Receiver in Energy Track

Problem Summary - Inadequate warning or annunciation of a shift in Loran-C operation which caused a constant calculated track bias and significant deviations from the desired track.

Discussion

This particular discrepancy occurred in the arrival segment (V-G) during the NAS testing portion (see Figure 5.3). This discrepancy is believed to be caused by the Loran-C receiver operating in energy track (dead-reckoning mode) as a result of temporary loss of Loran-C signals by the receiver. For some reason, this caused a noticeable shift in the Loran-C calculated data. The flight crew had no warning indication of a deterioration in the accuracy of the indicated track data. As a result of the bias error introduced by this shift, the aircraft was flown approximately 1.6 nm left of the desired track for an along track period of 10 nm (5 minutes). This type of system accuracy degradation is considered unacceptable without a positive indication of the validity of the navigation information displayed.

Impact

Unacceptable airspace deviations and pilot disorientation can occur due to the temporary loss of Loran-C signals. A suitable warning or mode annunciator should be provided in the primary scan of the pilot.

5. Loss of Magnetic Variation Stored Data

Problem Summary - Unsuspected and unannounced dropouts of stored magnetic variation data occurred during the flight test program.

Discussion

The loss of previously stored magnetic variation data was documented twice during the Loran-C flight test program. This data dropout occurred on two different flights on separate days. The first time the discrepancy was noted was during an in-flight portion, the other during the normal pre-flight check procedures. In both instances, discrepancies were corrected by re-entering the desired magnetic variation (10° west). Normally the magnetic variation was not entered prior to each flight, because once it was entered, it was stored in the Loran-C navigator permanent memory even after the set was turned off. Whenever the Loran-C navigator would be turned on, all previously stored information would be available to the pilot.

Impact

The loss of magnetic variation could lead to pilot/crew confusion due to the disagreement between the magnetic compass and the Loran-C course reading. However, since the pilot's cross track deviation needle is driven by the latitude and longitude position data from the Loran-C, there would be no effect on navigation accuracy.

6. Parallel Offset Input Procedures Are Too Complex

Problem Summary - Six discrete operations are currently required to properly input a parallel offset track with the current Loran-C navigator. Each of these operations presents opportunity for input error. These six operations could be replaced by a simple software change and a single parallel offset function key.

Discussion

In the tested configuration of the TDL-424 Loran-C navigator a total of six steps were required by the pilot to enter a given offset, as follows:

- Set DISPLAY switch to DSRTK/TKE
- Set the L/L-TD switch to TD
- Depress the CLR and GRI keys
- Select left or right of nominal course by depressing W 4 or E 6 keys
- Enter via the keyboard the offset distance you want, to within 0.1 nautical miles
- Depress INSERT

The input procedure required to enter the offsets caused hesitation by the pilots several times regarding which step was required next to properly enter an offset. No specific set of data was recorded applicable to the time required to input an offset. But it was observed that although some offsets were entered in approximately 10 seconds or less, others took as much as 40-50 seconds. The chances of entering the wrong offset are considerably increased in periods of high cockpit workload as was observed in the execution of the SAR patterns and impromptu offset clearance in the NAS testing portion. In fact, out of the 36 total offsets entered in the Loran-C navigator during the course of this project, three offsets (8%) resulted in the documentation of pilot input offset error.

An additional minor comment concerning the entering the offsets is the pilot's requirement to keep track of the decimal place. That is, the basic design of the Loran-C navigator allows the pilot to enter offsets from a minimum distance (offset) of 0.1 nm to 30.0 nm, but, there is no decimal place input in the Loran-C navigator. Rather, the pilot when entering an offset, i.e., 3.0 nm, must enter two digits 3 and 0, likewise 0.5 nm offset, must be entered using the 5 digit only. Although no errors were recorded due to this required procedure, it is suspected that the absence of a decimal place entry requirement specifically when entering offsets should be considered a blunder potential.

Impact

An unacceptable amount of pilot/crew input workload, data verification and memorization of input procedures is required to properly input a parallel offset track. This entire operation is currently error prone as indicated by the blunder summary of Section 5.4.

7. Rejection of Parallel Offsets

Problem Summary - In the initial portion of the flight test program the Loran-C navigator had an apparent software problem which randomly affected the parallel offset input capability.

Discussion

Several times during the input of parallel offsets, the Loran-C navigator did not accept a pilot's correct offset data entry. In each case a previous offset had been satisfactorily entered. However, the Loran-C navigator in each case removed the previous entered offset, but rejected the new one being entered. As many as three attempts were required by the pilot before the Loran-C navigator would accept the new offset entry. This particular problem seemed to be corrected after the TDL-424 Loran navigator was returned from its manufacturer following troubleshooting and corrective action of this and other discrepancies noted in the initial portion of the Loran-C flight test program.

Impact

No significant impact since the problem was corrected. However, production units should be thoroughly evaluated during acceptance testing to avoid re-occurrence of this problem.

8. Marginal Identification of Offsets Entered

Problem Summary - The current display of navigator operation in the parallel offset tracking mode is not continuous.

Discussion

The Loran-C navigator in its present configuration provides for the identification of offsets entered. But it requires the pre-selection of the DSRTK/TKE display operating mode to verify its magnitude and direction (right or left). If the offset is right, an "R" is shown on the display and an "L" is shown for left. However, on extended periods of time or frequent change of offsets, it was observed that the pilots had a tendency to forget which offset was entered in the Loran-C navigator. This was observed twice with different pilots, who forgot to deselect offsets after the conclusion of the expanding square pattern during the transition (leg change) to the return segment to CAPE MAY. In both instances the observer had to remind the pilot to deselect the offset.

Impact

Unacceptable deviations from ATC-initiated parallel offset tracks could occur due to a lapse in pilot memory regarding the input data. Also, as indicated in the SAR tests, returning to a ground based location (such as a hospital) after a rescue could be complicated if the parallel offset was not remembered or recognized and cancelled.

9. Rejection of Leg Change While on TIME/BRG Display Mode

Problem Summary - A possible leg change/mode selection interaction exists which is undesirable.

Discussion

Once the Loran-C navigator did not accept a leg change input while on TIME/BRG display mode. This particular discrepancy occurred while executing a sector search pattern. The pilot had to select DTW/XTK display mode for Loran-C navigator to accept leg change entry. As a consequence of this, the first cross-leg of this particular sector search pattern (Figure 5.7(b)) was poorly flown.

Impact

Possible airspace utilization problem.

10. At the Present Time the Loran-C Navigator Does Not Provide Bearing Display Information

Problem Summary - After the Loran-C navigator was returned from its manufacturer where adjustments to the system were performed, it was found that the Loran-C navigator no longer provided bearing display information.

Discussion

None

Impact

This error precluded completion of the desired six sector search patterns which rely on intercepting a desired bearing to or from the datum. It is assumed that this will be fixed in the production units.

11. Lighting

Problem Summary - The lighting of the Loran-C navigator displays was considered inadequate.

Discussion

The gain of the brilliance control was insufficient during sun glare conditions. Direct sun glare make it nearly impossible to read the illuminated displays.

Impact

Additional crew workload in trying to decipher the displayed information could adversely impact NAS or SAR operations and accuracy.

12. Unique System Bias Characteristics Observed

Problem Summary - NAS, SAR and surveillance testing produced data which identified a consistent and repeatable navigation bias error.

Discussion

An analysis of the aircraft total system cross track error difference between the actual and desired cross track indicated that the error is primarily due to the presence of a "bias" in the Loran-C algorithm. Only the following Loran-C transmitters were used during the Loran-C flight test program. The master transmitting station located at Cape Fear, North Carolina/ a secondary station at Nantucket, Massachusetts; and the second secondary station at Dana, Indiana. Upon analysis of the aircraft actual cross track, as determined from the EAIR radar tracking plots, it becomes evident that, depending on a particular aircraft heading, the resultant aircraft actual cross track is either left or right of desired track by a magnitude of approximately ± 0.4 nm. Further analysis reveals that on certain aircraft headings the aircraft total system cross track error (TSCT) becomes negligible or is zeroed out.

A correlation of edited TSCT data from flights (NAS) without updating the Loran-C navigator as a function of desired track heading is presented on Figure 5.13. The plot shown in Figure 5.13 is characterized by its sinusoidal shape with an amplitude of approximately ± 0.4 nm. Note that the TSCT error zeroes out whenever in the 90° and 270° region. The reason for this is that when the aircraft is flying in a latitudinal direction the bias error becomes an along track error. Similarly when on the 0° and 180° region the aircraft is flying in a longitudinal direction the bias error therefore becomes cross track error. The trend of the bias was based on a limited number of 8 data samples (different desired track headings) from the various segments flown in the NAS testing portion. The repeatability characteristics of the bias presented in Figure 5.14 suggests that the bias is due to the constant signal propagation velocity of the Loran-C navigator.

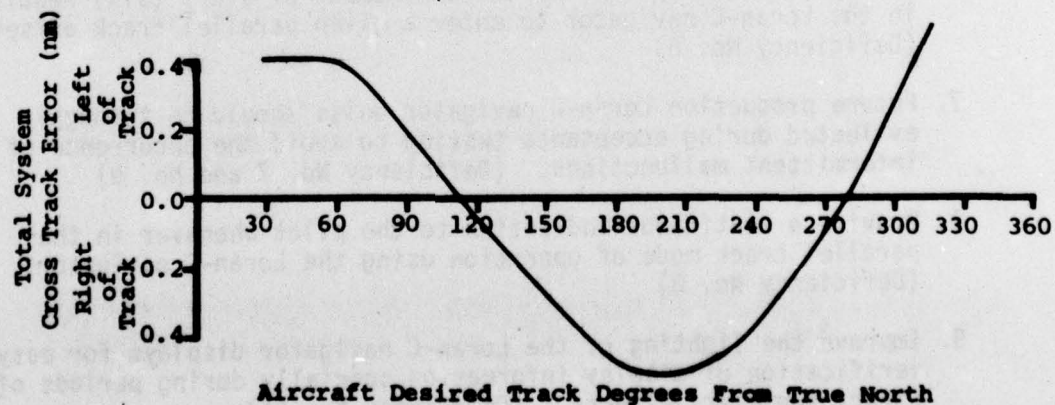


Figure 5.14 Loran-C Bias Error

Impact

Although the overall Loran-C accuracy was acceptable for all operations tested, repeatable bias errors are disconcerting. In the case of the particular stations used for this test, the bias was acceptable. However, similar biases may or may not exist and may or may not be of such small magnitude. Since this type of error is easily understood, readily documentable and easy to calibrate out once properly identified, additional flight testing and analysis should be performed using other Loran-C station pairs to eliminate this error source.

5.2.2 Recommendations

The following recommendations are based on the deficiencies documented in the previous Section 5.5.1.

1. Improve the location of the TO/FROM flag indicator driven by the Loran-C navigator so that it will be within the normal scan pattern of the pilot. (Deficiency No. 1)
2. The Loran-C navigator should provide the same parallel offset track distance regardless of either automatic or manual mode methods of waypoint selection. (Deficiency No. 2)
3. The automatic sequencing of waypoints in the Loran-C navigator should be performed as a function of TO/FROM flag change and Distance-To-Waypoint. (Deficiency No. 3)
4. Provide a suitable warning indicator to the pilot whenever the Loran-C receiver is in dead-reckoning mode (Energy Track) due to temporary loss of Loran-C signals. (Deficiency No. 4)
5. Improve safeguards in the Loran-C navigator to avoid the loss of stored data as in the case involving the unsuspected and unannounced dropout of stored magnetic variation data during the flight test program. (Deficiency No. 5)
6. Reduce and/or simplify the current number of steps (six) required in the Loran-C navigator to enter a given parallel track offset. (Deficiency No. 6)
7. Future production Loran-C navigator units should be thoroughly evaluated during acceptance testing to avoid the occurrence of intermittent malfunctions. (Deficiency No. 7 and No. 9)
8. Provide a continuous indication to the pilot whenever in the parallel track mode of operation using the Loran-C navigator. (Deficiency No. 8)
9. Improve the lighting of the Loran-C navigator displays for easy verification of display information specially during periods of direct sun glare effects. (Deficiency No. 11)

10. Additional Loran-C flight tests should be performed to quantify the extent, magnitude and characteristics of the documented system bias in the Loran-C flight test program. (Deficiency No. 12)

The recommended Loran-C flight tests should include evaluation of the Loran-C navigator at different geographical locations and covering the continental U.S. Coastal Confluence Zone (CCZ).

Also, the tests should be performed by utilizing the Loran-C signals from various Loran-C station pairs. It is believed by quantifying and mapping the bias error, since it appears to be repeatable as well as predictable, the incorporation of a filter or software correction in the Loran-C navigator could offset the error caused by the bias.

11. Provide a distance-to-waypoint (DTW) display indicator in the pilot's front instrument panel.

The addition of a DTW display indicator will contribute significantly to a greater reduction of blunders, cockpit workload and head down time. The location of the DTW display indicator should be relatively close to the cross track error indicator and TO/FROM indicator display, respectively. This arrangement would make the pilot's scanning of the navigation flight instruments/displays combination easier and more affective.

12. Determine the feasibility of incorporating programmable features in the Loran-C navigator so that most common types of SAR pattern could be flown without necessitating a continued data entry by the pilot.

It is felt that the Loran-C navigator in its present configuration will be an invaluable tool to the SAR flight crew in the execution of SAR patterns as compared to presently utilized conventional navigation methods. However, the addition of programmable selected features to the Loran-C navigator will improve its effectiveness during a SAR type mission. For instance, the ability to pre-program a given SAR pattern would allow the pilot to fly the indicated track and would relieve considerably the workload required in having to provide new data entries at required intervals during the SAR pattern. A creeping line pattern is a typical example of this as it required the crew, in the tested Loran-C navigator configuration, to constantly interchange the waypoints defining the initial (reference) leg every time a new leg was begun. In addition, the pilot had to remember to select the specific required offset (right or left) and at the same time to keep track of the various legs flown. This was required so that the magnitude of the offset to be entered next would correspond to the actual cross track distance from the desired leg to the referenced initial leg. In the execution of the SAR patterns flown in the Loran-C flight test program in just about every case, the pilot's had to use "bookkeeping" on their knee pad to record the progress of their flight. Undoubtedly, the required revision of the Loran-C navigator design to automatically navigate an entire SAR pattern without

necessitating a continued data entry by the pilot requires a thorough analysis. However, it is thought that because of the consistent structure of SAR patterns, the required input data to perform the pertinent computations are common to each of the SAR patterns. These primary data input parameters are track spacing, leg length and CSP or datum waypoint definition in lat/lon time difference.

13. Carefully develop proper operational search and rescue Loran-C flight training including flight planning procedures to insure the proper and logical sequencing and labeling of waypoints. These planning and training efforts should concentrate on logical waypoint input sequences and numbering (1.2.3,....9) to avoid confusion during a SAR. Also, these procedures should be tailored to integrate with preplanned SAR profile data if available on production models of the Loran-C navigator.

6.0

SUMMARY OF RESULTS

This section presents an overall summary of the quantitative results obtained from the operational flight testing of the Loran-C navigator. The results summarized in this section are introduced, explained and analyzed in detail in Section 5.0 "Discussion of Results and Analysis". To provide an easy cross reference, the results summary subsections: 6.1, 6.2, 6.3, etc., correspond directly to the subsections of Section 5.0 where the corresponding results are discussed.

The quantitative results summarized in the following paragraphs were used to derive the more general qualitative conclusions presented in Section 7.0.

6.1 NAS/AC 90-45A ACCURACY COMPARISON

The Loran-C demonstrated total system accuracy was analyzed using two techniques. First, the measured deviation from desired track was calculated for enroute, terminal and final approach data by aggregating statistics from the NAFEC precision tracking radar. Second, the measured airborne equipment error was combined with the flight technical error specified in AC 90-45A using the recommended Root-Sum-Square (RSS) technique. The results presented in this summary will include both sets of data.

- 1) Enroute the Loran-C navigator system performed well within the AC 90-45A specified accuracy limit of ± 2.5 nm.
 - a) Measured total system cross track accuracy (TSCT) was ± 0.56 nm two sigma.
 - b) Calculated TSCT was ± 2.08 nm two sigma using the AC 90-45A specified ± 2.00 nm two sigma flight technical error (FTE) value and combining it, using the RSS method, with the measured ± 0.57 nm two sigma airborne equipment error.
- 2) The terminal area maneuvering data demonstrated track keeping accuracy within the specified AC 90-45A limit of ± 1.5 nm.
 - a) Measured TSCT was ± 0.51 nm two sigma.
 - b) Calculated TSCT was ± 1.11 nm using the AC 90-45A specified ± 1.00 nm two sigma FTE and combining it, using the RSS method, with the measured ± 0.49 nm two sigma airborne equipment error.
- 3) Non-precision Approach Data - Non-precision approaches were flown using three different methods of inputting the final approach waypoints. The three methods were, first, using non-updated latitude and longitude waypoint coordinates taken from the experimental navigation chart. Second, using the same latitude and longitude waypoint coordinates taken from the chart but updating the Loran-C navigator position using a

known location prior to take off. (This is typical of airline quality latitude/longitude area navigation systems which are updated with gate or ramp position prior to departure). The third input technique used measured time difference coordinates to define waypoint location. This input procedure would be typical of an operator with a fixed route structure. Once an approach has been made, the time differences over the final approach fix, the outer marker, the inner marker, etc. can be recorded. On subsequent approaches, the Loran-C will provide accurate guidance directly to those precise waypoints.

A. Non-Updated Latitude/Longitude Input

- i) Measured TSCT was ± 0.10 nm two sigma.
- ii) Calculated TSCT was ± 0.50 nm using the AC 90-45A specified ± 0.50 nm two sigma FTE and combining it, using the RSS method, with the measured ± 0.04 nm two sigma airborne equipment error.

B. Updated Latitude/Longitude Input

- i) Measured TSCT was ± 0.06 nm two sigma.
- ii) Calculated TSCT was ± 0.50 nm using ± 0.50 nm FTE and ± 0.03 nm two sigma airborne equipment error combined by RSS.

C. Time Difference Input

- i) Measured TSCT was ± 0.12 nm two sigma.
- ii) Calculated TSCT was ± 0.50 nm using ± 0.50 nm FTE and ± 0.05 nm two sigma airborne equipment error combined by RSS.

The overall analysis has shown that the Loran-C system satisfies AC-90-45A non-precision approach compliance criteria for all three modes of waypoint input.

6.2 SAR ACCURACY ANALYSIS

Creeping line, sector and expanding square searches were performed. The primary analysis was performed by inspection of the radar tracks compared to the desired patterns. Track keeping anomalies were explained using the airborne Loran-C observer's logs. Those comparisons are shown in Section 5.2 Figures 5.6, 5.7, 5.8 and 5.9. Both Loran-C flights and comparison flights using conventional VOR/DME navigation were analyzed.

- 1) The magnitude of actual cross track errors from the desired creeping line pattern using the Loran-C navigator was approximately 0.2 nm and uniformly distributed along each search leg.
- 2) In contrast, using conventional VOR/DME navigation, errors of up to 1.0 nm were observed.
- 3) The Probability of Detection (POD) using Loran-C was calculated as 77.33% on the first pass of a creeping line search.
- 4) The POD using conventional VOR/DME was calculated as 68.4% on the first pass.
- 5) The POD results indicate that a 31% reduction in the number of searches required to achieve 78.00% POD is achievable using Loran-C compared to VOR/DME navigation.
- 6) Sector search patterns flown using the Loran-C navigator were much more compatible with the desired track than those flown using VOR/DME. See Figure 5.7 for the illustration of these results. No POD was calculated for the sector searches.
- 7) The expanding square search patterns flown using the Loran-C navigator were within 0.4 nm of the desired track regardless of the route segment being flown (See Figure 5.8).
- 8) In contrast, the conventional VOR/DME expanding square searches displayed large deviations from the desired track which exceeded 1.0 nm in some cases. See Figure 5.9 for the illustration of these results. No POD was calculated for the expanding square searches.

6.3 SURVEILLANCE ACCURACY RESULTS

Three buoys, a lighthouse and a VORTAC were used to obtain Loran-C accuracy and repeatability data for surveillance and oil rig location data. Mean Position Errors and Circular Error Probability (CEP) statistics were computed for each target and for the combinations — all buoys and all targets.

- 1) If the position of a known charted buoy or oil rig is to be checked or returned to daily, the mean Loran-C position error was found to be 896 feet with a CEP of $(114.3 \pm 3\%)$ feet.
- 2) If it is desired to know the accuracy with which the Loran-C can locate an entire group of buoys in a given channel or an entire set of oil rigs, then the statistically aggregated CEP of $(295.9 \pm 3\%)$ feet should be used. The mean error remains the same at 896.0 feet.

- 3) If the CEP for an entire population of objects (buoys, oil rigs, lighthouse, VORTACs, hospitals) is desired, then the Loran-C mean position error of $(377.0 \pm 3\%)$ feet should be used.

6.4 BLUNDER RESULTS

The intended use of the blunder data recorded was to define functional, input and human factors characteristics of the prototype Loran-C system for feedback to the USCG and the manufacturer to use in the development of production versions of the system. No long term pilot training was provided in the use of the Loran-C system and no special efforts were made to select test subject pilots with previous Loran-C or digital avionics experience. The blunders recorded should be considered indicative of the learning process.

- 1) A total of 21 blunders were recorded during the 14 data collection flights flown by 6 subject pilots.
- 2) Only 7 of the 21 blunders were serious enough to cause either a violation of the AC 90-45A accuracy limits or affect the SAR mission performance.
- 3) Section 5.4 describes each of the blunders in detail including type of error, where it occurred, and effect on the mission.

6.5 OPERATIONAL DEFICIENCIES RESULTS

Section 5.5.1 summarizes each of the operationally significant problems encountered during the performance of the Loran-C navigator flight test program. Problem types include Loran-C software, display, input workload, and biases.

- 1) There were 12 operational deficiencies noted during the flight test program which were judged significant enough to warrant further investigation by the USCG. These are thoroughly discussed in Section 5.5.1 including an assessment of the impact.
- 2) None of the 12 deficiencies caused any significant loss of operational data or impacted the validity of the statistical results obtained in any way.

The major conclusions from the operational flight test evaluation of the Loran-C navigator are summarized in this section. These conclusions are, by intent, qualitative in nature. The quantitative results from which these conclusions were reached are summarized in Section 6.0 and discussed in depth in Section 5.0. These conclusions are organized in the order of the general program objectives stated in Section 1.1. Following the statement of a conclusion regarding each general objective are summary conclusions for the more detailed evaluation objectives presented in Section 3.0.

- 1) The Loran-C navigator system performed accurate, repeatable and operationally meaningful search and rescue missions including creeping line, sector and expanding square search patterns.
 - The performance of the Loran-C navigator on these SAR missions demonstrated the suitability of the system for use operationally on the HH-52A helicopter.
 - From a navigation accuracy viewpoint, the results obtained indicate that the Loran-C navigator is capable of utilization on other helicopters and other fixed wing aircraft.
- 2) The Loran-C navigator system demonstrated superior performance of all search and rescue patterns compared to conventional USCG navigation techniques.
 - The functional and data storage capability provided by the Loran-C navigator reduced crew workload during the performance of all SAR missions, which provided more time for the accurate flying of the aircraft and execution of the desired pattern.
 - The accuracy and repeatability of the Loran-C navigator system provided more consistent search area coverage and more reliable patterns than were demonstrated using conventional VOR/DME navigation techniques.
- 3) The Loran-C navigator system demonstrated a mean position error of less than 900 feet and a circular error probability of less than 400 feet for all surveillance targets tested.
 - The applicability of Loran-C as a method of enhancing USCG surveillance and enforcement capabilities was adequately demonstrated.
 - Loran-C demonstrated the capability of providing accurate and repeatable navigation in an offshore environment.

- The feasibility of using Loran-C to verify bouy positions was demonstrated.
 - Loran-C provided accurate navigation overwater where inadequate VOR/DME coverage generally exists such as in offshore oil rig operations.
- 4) The suitability of the Loran-C navigation system in the current National Airspace System VOR/DME environment was adequately demonstrated.
- No degradation in navigation accuracy or functional performance was observed using the Loran-C navigator compared to current VOR/DME equipped aircraft.
 - The HH-52A helicopter integrated easily in enroute, terminal and final approach operations with conventionally equipped aircraft.
 - The HH-52A helicopter did not encounter or precipitate any airspace or procedural conflicts in entering or departing Cape May Air Station, NAFEC or the shoreline.
- 5) The compatibility of a Loran-C navigation system with both present and planned area navigation routes and procedures was adequately demonstrated for enroute, terminal and final approach operations. These tests were performed without any special system update or initialization procedures.
- Enroute operations remained within ± 1.0 nm of desired track compared to the AC 90-45A requirement of ± 2.5 n.
 - Terminal operations remained within ± 0.6 nm of desired track compared to the AC 90-45A requirement of ± 1.5 nm.
 - Non-precision final approach operations were within the AC-90-45A limit of 0.6 nm of all three waypoint input modes tested.
- Those modes were:
- i) Non-updated lat/lon input of charted waypoint coordinates.
 - ii) Updated lat/lon input of charted waypoint coordinates using known gate location prior to departure.
 - iii) Calibrated time/difference coordinates input for waypoint locations.
- 6) The Loran-C navigator system demonstrated extremely accurate performance in flying non-precision approaches using measured time/difference waypoint input coordinates.

- 7) The Loran-C navigator system performed satisfactorily in offshore surveillance and search and rescue missions where VOR/DME coverage is inadequate. This performance should be of special interest to off-shore helicopter operators.
- Three moored buoys at depths of 16, 52 and 90 feet were repeatedly located with a mean error of only 896 feet and a circular error probability (CEP) of 296 feet.
 - Brandywine Lighthouse in Delaware Bay was repeatedly located with a mean error of 957 feet and a CEP of only 114 feet.
 - Sea Isle VORTAC (Inland) was repeatedly located within a mean error of 246 feet and a CEP of only 86 feet.
 - All SAR missions were flown within approximately 0.4 nm of the desired search pattern and without significant degradation in probability of detection.

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